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COMMUNITY NOISE EXPOSURE RESULTING FROM AIRCRAFT OPERATIONS: APPLICATION GUIDE FOR PREDICTIVE PROCEDURE

BOLT BERANEK AND NEWMAN, INCORPORATED

PREPARED FOR

AEROSPACE MEDICAL RESEARCH LABORATORY

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This report is one of a series describing the research program undertaken by the Aerospace Medical Research Laboratory to develop procedures for predicting the community noise exposure resulting from aircraft operations. It discusses the applications of the procedure to the aircraft noise-related problems facing master planners, civil engineers, environmentalists, etc., as well as the management people concerned with operating an air

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base. Examples are given of use of the procedure in terms for land planning, operational applications at air bases and basic aircraft design. This noise exposure prediction procedure updates the composite noise rating (CNR) methodology used by the three military services and the civil aviation community since 1964. The procedure described is the noise exposure forecast (NEF) procedure which utilizes the effective perceived noise level (EPNL) as a basic noise measure to describe the noisiness of a given aircraft operation. Since the basic principles are similar, the procedure can be easily rescaled in terms of the day/night average level (DNL) which has recently been recommended by the Environmental Protection Agency as the basic noise exposure measure for both airport and non-airport situations.

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FOR THE COMMANDER

Henning E. von Gierke

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SUMMARY

This report is one of a series describing the contractual and in-house research program undertaken by the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, to develop a procedure for predicting the community noise exposure resulting from aircraft operations. It discusses in lay terms the applicability of the procedure to the aircraft noise related problems facing the master planners, civil engineers, environmentalists, etc., as well as the management people concerned with operating an air base. The referenced companion reports are:

- Ref. 7 Describes the rationale and technical basis for the noise exposure prediction procedure.
- Ref. 8 Describes the measurement test plan and data analysis methodology used to obtain the required data file on military aircraft noise characteristics.
- Ref. 9 Describes the capability of the noise exposure prediction computer program and how the user can avail himself of its many features.
- Ref. 10 Describes the set of routines making up the noise exposure prediction computer program.
- Ref. 11 Describes the results of acoustic measurements made during various Air Force and Navy/Marine Corp. aircraft ground and flight operations.

This new noise exposure prediction procedure updates the Composite Noise Rating (CNR) methodology used by the three military services and the civil aviation community since 1964 when it was first published as AFM 86-5, TM 5-365, and NAVDOCKS P-98, "Land Use Planning With Respect to Aircraft Noise."

This and companion reports, together with the accompanying computer program, are based upon the noise exposure forecast (NEF) procedure which utilizes the effective perceived noise level (EPNL) as the basic measure for describing the noisiness of a given aircraft operation, whether it is a B-52 takeoff, a C-130 ground runup, a T-38 touch and go, or whatever. The EPNL noise measure accounts for the signal level, frequency content, presence of pure tones, and the duration of the noise in computing a single number index of the relative noisiness or annoyance associated with a single aircraft operation. The weighting of the frequency content is based upon the results of psychoacoustic studies, specifically designed to judge relative noisiness. While the effective perceived noise level is recognized by most acousticians as the most accurate measure of

annoyance from aircraft noise, other measures are used when a decrease in accuracy can be offset by cost, simplicity of measurement, or other consideration.

Recent studies by the Environmental Protection Agency have led to the specification of another noise exposure procedure and measure, the day/night average level (DNL) which utilizes the sound exposure level (SEL), the A-weighted sound level integrated over the time of the event, as the basic measure of the noisiness of a given event -- aircraft takeoff, ground runup, etc. In view of EPA recommendations regarding the use of DNL as the basic noise exposure measure in describing noise not only around airports, but also as a measure of noise exposure for non-airport situations, it is recommended that the DNL (with tone correction and ground runup penalty modifications as described in Ref. 7) be adapted as the basic noise exposure procedure to describe Air Force operations. The NEF procedures and computer program can be easily rescaled in terms of DNL since the basic principles underlying NEF and DNL procedures are similar. In addition, the military aircraft noise data file contains descriptions of noise in terms of both effective perceived noise level and the sound exposure level (as well as other measures based on the perceived noise level and A-level).

Changes in missions, flight operations, or aircraft types can cause major changes in the noise environment which can drastically undermine existing land use strategies at a particular air base. Such problems arising from major changes in the noise environment illustrate the very real need for early assessment of the environmental impact. Using the noise exposure procedures (NEF or DNL) with the present and anticipated average number of aircraft operational conditions at a given air base clearly reveals the expected changes in the noise environment in the vicinity of the air base, the anticipated community response to these changes in the noise environment, and land uses compatible with the noise environment. Thus, the procedure not only can be used for land use planning purposes as in the Air Installation Compatible Use Zone (AICUZ) program recently adopted by the Department of Defense, but can also be used in gaming studies for evaluating the effect on the noise environment due to changes in aircraft assignment or flight operations, new propulsion systems or aircraft types, for siting of ground runup facilities or identifying engine test cell and ground runup suppressor needs, and for unveiling possible means of alleviating community annoyance "hot spots" about an air base.

With the single event noise data file describing the noisiness produced by each aircraft type as a function of engine power setting and the performance characteristics of the aircraft, the procedure computes for any specified location on the ground the total noise exposure over a 24-hour period resulting from the average number of ground runup and flight operations occurring at the air base. This noise exposure is then weighted for the increased annoyance associated with nighttime operations and ground runups to yield the NEF value at that location. To graphically describe this weighted noise exposure the NEF value is computed at 1000 foot intervals and contour lines plotted on a vicinity map by connecting points of equal NEF value.

Provided in this report are guidelines for interpreting the NEF value in terms of percentage of the exposed population that will be highly annoyed and expected to complain and land uses identified that are compatible with a given noise exposure. To apply the procedure, accurate information is required of the air base layout, operational procedures, flight data, and ground runup information. Sample forms are included to report the necessary data in a standard format.

PREFACE

The author wishes to acknowledge the assistance of Nicolaas H. Reddingius in the preparation of Section II of this report, and the specific contributions of Richard D. Horonjeff and Nicolaas H. Reddingius in preparing Appendix A, the information requirements for air base noise analyses.

The many discussions of contents and emphasis with Dr. William J. Galloway, BBN, and with Jerry D. Speakman and John N. Cole of the Biodynamics and Bionics Division, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, have been of great assistance.

This work was performed for the Aerospace Medical Research Laboratory under Project/Task 723104 Measurement of Noise and Vibration Environments of Air Force Operations. Funding was provided by the Air Force Weapons Laboratory to partially support this development.

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SECTION I

INTRODUCTION

Noise from aircraft operations impacts on many facets of Air Force operations. This has been recognized by the Air Force in the many research and development studies and operational steps taken to control aircraft noise since it was first identified as more than an occasional problem in the early 1950's. Despite the many steps, most military aircraft remain noisy and, with the continuing need for maximum performance to carry out primary military tasks, many future aircraft will also be noisy.

The sharply increased emphasis on environmental factors within the last few years and the recognition of noise pollution as a problem of national concern means that noise from aircraft operations must receive even more attention than in the past.

There is particular need for better assessment of the actual noise environment around air stations, increased consideration of noise in operations and air base planning, and more exploration of means for reducing noise exposure. To aid in this effort, the Air Force has developed new procedures for depicting the aircraft noise environment around air bases. These new procedures result in the calculation of noise exposure forecast (NEF) contours to depict the noise environment.

The NEF contours represent a major updating of the composite noise rating (CNR) contours that have been widely used to depict the noise environment around military air bases.

This report briefly describes the NEF procedures. More importantly, the report describes the applications of the NEF contours and procedures to a number of aspects of Air Force operations -- air base planning, aircraft operations and aircraft design. The report also provides interpretations of the noise contours in terms of impact on land development and on community response around air stations.

This report does not provide great technical detail about the NEF procedures or its applications, since such information is provided in the references given. The only exception is Appendix A which provides a detailed guide, together with the necessary data forms, for the collection of the information needed to calculate the noise exposure contours for a specific air base.

Consideration of noise involves special terminology and concepts that may not be familiar to the reader. Thus, the next section of this report provides a brief review of noise fundamentals and an introduction to aircraft noise terminology.

SECTION II

AIRCRAFT NOISE BASICS

The word *noise* is in wide use in many field of technology today, but if we limit our discussion to its use in relation to sound, one may define noise loosely as *unwanted sound*. For our purposes, an acceptable definition of *sound* is that it is a physical disturbance of the atmosphere that can be detected by the human ear. A simple source of sound familiar to all of us is the tuning fork. When it is struck, it vibrates in a to-and-fro motion setting the air in motion in the same manner. This resulting disturbance of the air travels outward from the tuning fork and upon entering the ear canal of the listener produces an auditory sensation, or sound.

We are concerned in defining the impact of aircraft noise on people, on communities and on land uses. Before one can discuss these aspects, it is useful to discuss some properties of sound and develop some of the quantitative scales that are used in the measurement of sound. We will then discuss some of the special properties of sound generated by aircraft operations and give some insight in the human factors.

BASIC NOISE MEASURES

There are several attributes that we associate with a sound: it may be loud or faint, it may be high-pitched or low, discordant or pleasing, etc. These various characteristics must be quantified in order to arrive at an engineering description of any given sound and to have a means for comparing two sounds separated in space and time.

Decibel Scale

The pressure fluctuations in the quiescent atmosphere, which are detected as sound, are generally very small, but nonetheless there is a large difference in pressure between the faintest audible sound (e.g., rustling leaves) and the loudest sounds (jet engines, rockets). The ratio is on the order of a million billion (10^{15}). Although the human ear can distinguish the differences in loudness between these different sources, the differences in loudness are much smaller.

If a given sound source produces a certain subjective sensation of loudness, two identical sources will not be perceived as being twice as loud. Experiments have shown that the human ear, as well as certain other sensory functions, behaves in a non-linear way which is close to the mathematical logarithm function.

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Using this mathematical basis, it is possible to construct a scale for measuring the pressure fluctuations (sound pressure) which corresponds fairly well with the properties of the human ear as far as loudness perception is concerned. This scale is called the "decibel scale" and the quantity that it measures is called *sound pressure level.* The zero on this scale corresponds roughly to the quietest sound an average person can hear. A sound level of about 120 on this scale corresponds to the point where the noise becomes painful.

Figure 1 illustrates the logarithmic nature of the decibel scale; it shows a range of sound pressures ranging from 1 to 10,000 in magnitude translated into scale from 0 to 80 in decibels. Because of the *compression* inherent in the decibel scale, the addition of two sounds using the decibel scale is very unlike arithmetic addition. One example in Figure 1 shows that the addition of two noises of equal magnitude results in an increase of 3 dB. The second example illustrated in the figure shows that when one sound is appreciably larger than another, the addition of the lesser sound adds very little to the level of the combination. Figure 2 provides a chart and rules for the addition of two noise levels.

Frequency Spectrum

Apart from the loudness of a sound there is the characteristic of *pitch.* We have seen that the size of the pressure fluctuations in the air determine the loudness of the sound. The pitch of a sound is related to how often such fluctuations repeat. For audible sounds this repetition may vary from about 20 times per second to around 16,000 times per second. If a given sound consists of fluctuations which repeat 440 times per second we say that the sound has a *frequency* of 440 Hz.

There are various kinds of sounds. The sound produced by the simple tuning fork is known as a *pure tone* and is usually composed of a single frequency. An example of a more complex sound is a musical note such as Middle C on the piano. This kind of sound has a fundamental frequency (256 Hz) plus several overtones or harmonics. In practics one encounters sounds that are much more complex, such as *speech, music,* and the wide range of sounds classed as *noise.* Each of these sounds contains energy extending over a rather wide frequency range. This includes, of course, most aircraft noises, as well as the noise produced by most motor vehicles. One can identify the pure tone with the whine of a jet engine compressor or fan, and the broad band noise with the roar of the exhaust of a turbojet engine.

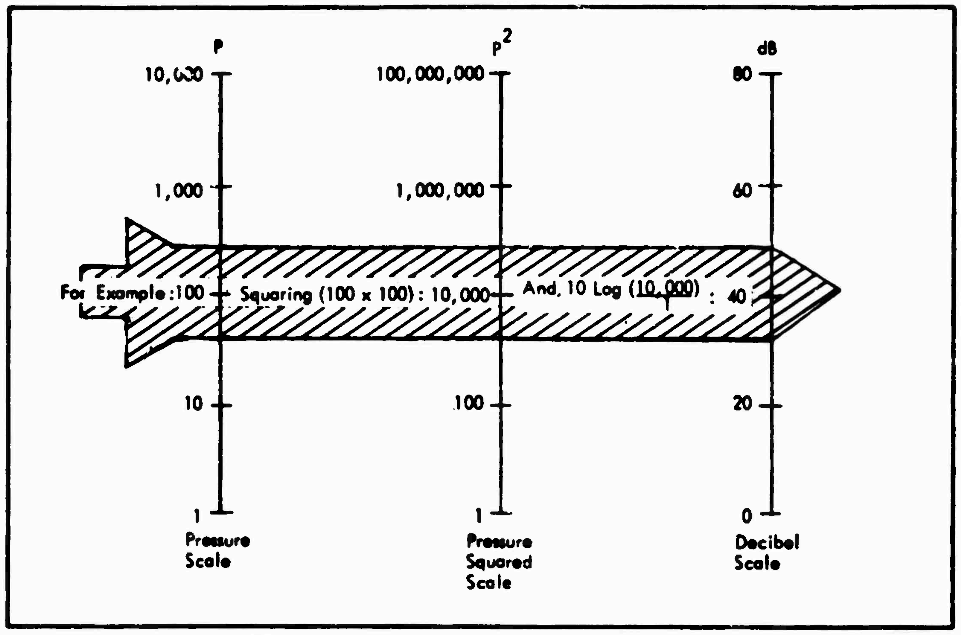
Figure 3 shows a typical frequency spectrum for a jet exhaust noise. In this instance, noise levels are measured in frequency bands, each an octave in width. The "total" sound level, called the *overall sound pressure level,* is the sum of the sound levels in each octave band (with addition in accordance with the rules given in Figure 2).

DECIBELS

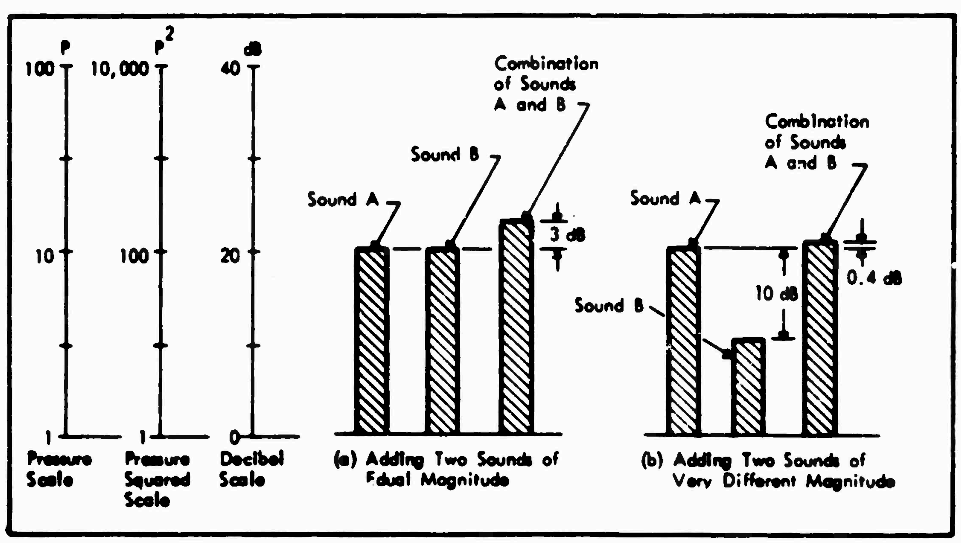
Sound Pressure Level $= 20 \text{ Log } \frac{p}{p_r}$

or $10 \text{ Log} \left(\frac{p}{p_r}\right)^2$

and $p_r = 0.0002$ Dynes/cm^2



The Logarithmic Nature of the Decibel



Addition of Sound Levels

FIGURE 1. ILLUSTRATING THE LOGARITHMIC NATURE OF THE DECIBEL

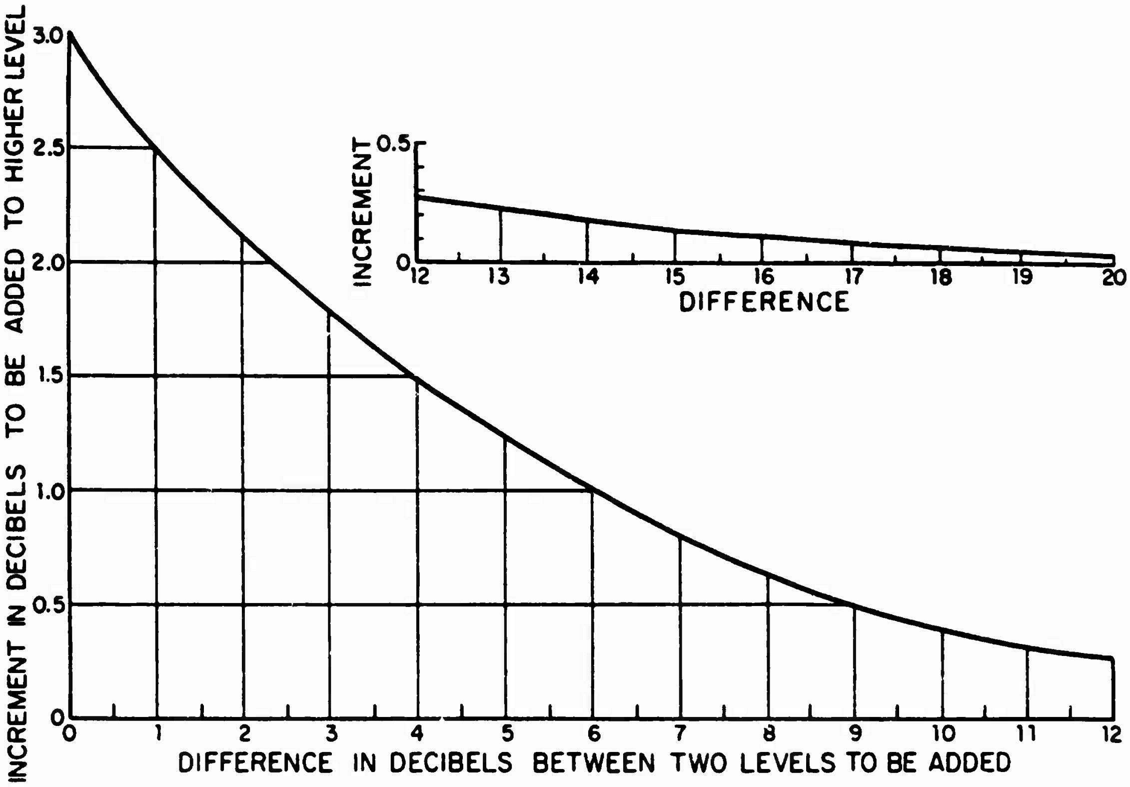


CHART FOR COMBINING SOUND LEVELS BY "DECIBEL ADDITION"

For noise levels known or desired to an accuracy of ± 1 decibel *:

When two decibel values differ by	Add the following amount to the higher value
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	

*** For greater accuracy, use chart above**

RULE FOR COMBINING SOUND LEVELS BY " DECIBEL ADDITION"

FIGURE 2. "DECIBEL ADDITION" RULE AND CHART

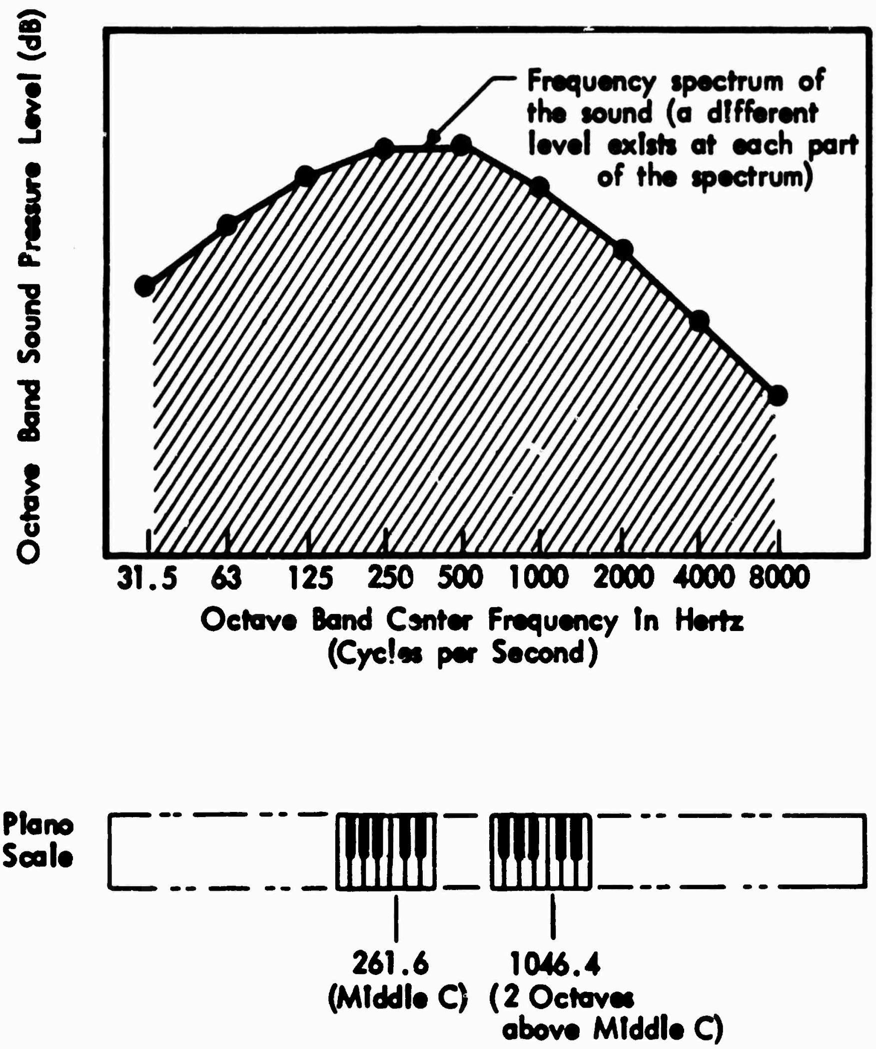


FIGURE 3. TYPICAL FREQUENCY SPECTRUM OF A JET EXHAUST

A-Weighted Sound Level

To complicate matters, the human ear is more sensitive to sound energy at higher frequencies than at lower frequencies, and further, the ear's sensitivity to sounds of different frequencies changes with the level (magnitude) of the sound. In problems involving people's reaction to noise, one needs a way of accounting for the ear's varying sensitivity to noises which vary in frequency and in level. And, much effort has gone into studies to develop improved methods of relating physical measurements to the subjective response of human listeners.

One early approach for improving the correlation between measured pressures and subjective human response was the introduction of frequency weighting networks on sound level meters*.

The weighting network that is in widest use today is the A-weighting network. The network discriminates against the lower frequencies, to which the ear is less sensitive, according to a relationship approximating a person's subjective reaction in terms of loudness at moderate sound levels. Noise levels with the A-weighting network are identified as the "A-weighted sound pressure level of 77 dB," or more simply as the "A level of 77 dB," or, shorter yet, as "77 dBA."

The lower part of Figure 4 shows the electrical frequency response of the A-scale network; the upper part of Figure 4 illustrates the effect of the filter on a typical jet noise spectrum.

The A-weighting is widely used throughout the world to measure community and industrial noise. It is also widely used to measure motor vehicle and traffic noise. Figure 5 lists the approximate A-level of some common sounds. The figure also shows the relative subjective loudness of the sounds, as well as the relative physical sound energy involved. The relative loudness scale shows that a change of 10 dB in the A-level corresponds to a subjective judgment of a halving or doubling of the loudness of the sound. In other words, a sound judged to be twice as loud as another sound would have a sound level approximately 10 dB greater than the first sound (even though the 10 dB change corresponds to a factor of 10 in actual sound energy). On the other hand, a difference of one or two dB between sounds, although probably detectable if heard within a short time interval, would not be judged to be significantly different in loudness by most observers.

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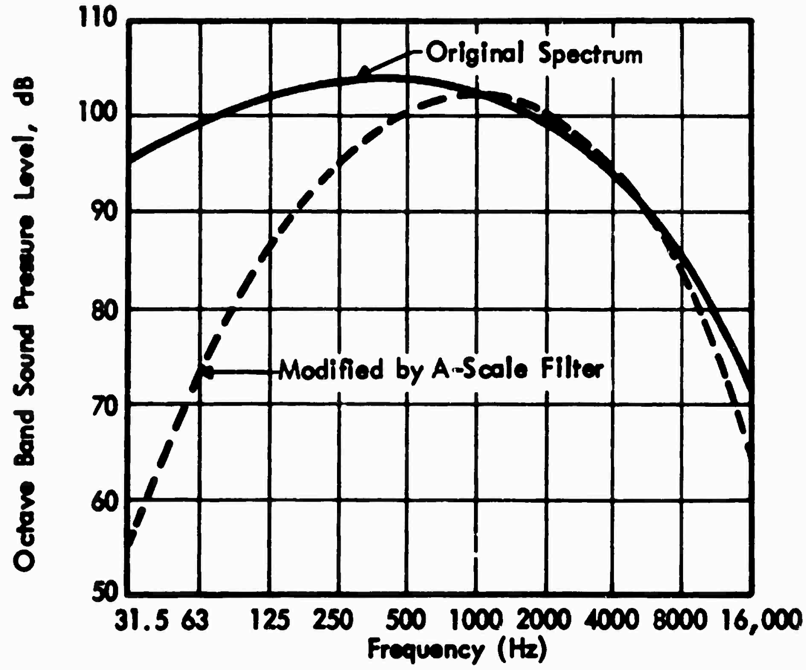
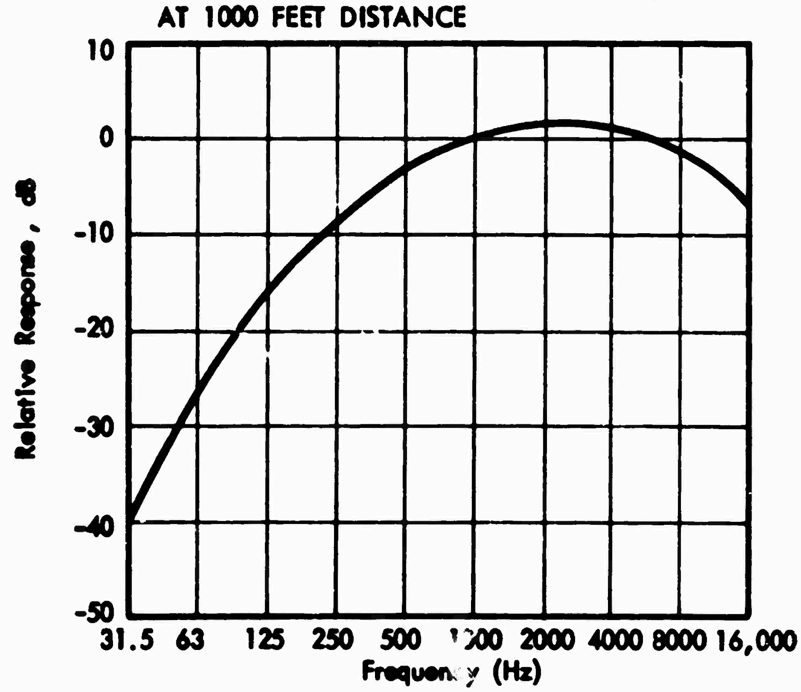
*The sound level meter is a device for measuring sound pressure levels. The small pressure fluctuations are detected by an extremely sensitive sensor called a microphone and are transformed into an electrical signal. By means of electronic circuitry this electrical signal can be amplified and read out on a meter directly in decibels.



A. GENERALIZED NOISE SPECTRUM OF TURBOJET AT 1000 FEET DISTANCE



B. ELECTRICAL FREQUENCY RESPONSE SPECIFIED FOR THE A-SCALE FILTER OF SOUND LEVEL METERS (ANSI S 1.4 - 1971)

FIGURE 4. ILLUSTRATING THE EFFECT OF THE A-SCALE FILTER

Sound	Sound Level[1] dB(A)	Relative Loudness (Approximate)	Relative Sound Energy
Jet Plane, 100 Feet	130	128	10,000,000
Rock Music with Amplifier	120	64	1,000,000
Thunder, Danger of Permanent Hearing Loss	110	32	100,000
Boiler Shop, Power Mower	100	16	10,000
Orchestral Crescendo at 25 Feet, Noisy Kitchen	90	8	1,000
Busy Street	80	4	100
Interior of Department Store	70	2	10
Ordinary Conversation, 3 Feet away	60	1	1
Quiet Automobile at Low Speed	50	1/2	.1
Average Office	40	1/4	.01
City Residence	30	1/8	.001
Quiet Country Residence	20	1/16	.0001
Rustle of Leaves	10	1/32	.00001
Threshold of Hearing	0	1/64	.000001

[1] U.S. Department of Housing and Urban Development Circular 1390.2

FIGURE 5. SOUND LEVEL OF COMMON SOUNDS

Perceived Noise Level

The advent of jet aircraft and particularly their wide use in commercial aviation renewed interest in arriving at a sound level scale which would correlate well with human response to the noise produced by jets. Jet engines produce considerable noise in the middle and high frequencies and therefore are judged much *noisier* than the propeller aircraft which produce a more low frequency noise. A model was developed which approximates a person's subjective response in terms of relative *noisiness* or *annoyance* of the aircraft sounds. The scheme is too complicated to be implemented by a simple filter, and requires summing up, in a particular non-linear manner, the noisiness contribution of each frequency band in the noise spectrum. This noise measure is called the perceived noise level (PNL). The unit of measurement is again the decibel, but a caveat is appended to the unit dB. The perceived noise level is therefore expressed in PNdB.

The perceived noise level has come into wide acceptance as a valid measure of aircraft noise although with some further refinements. The presence of identifiable discrete tones makes a noise more objectionable than it would be without these tones. This led to the tone-corrected perceived noise level (PNLT). The exact relationship between the A-level and the PNL or PNLT for a given aircraft sound will depend upon details of the noise spectrum. But, for most aircraft sounds there will be a rather close correlation between A-level values and the perceived noise levels; typically, the PNL will be 12 to 14 dB higher than the A-levels, thus, a rough rule-of-thumb for converting from one scale to another is:

$$\text{PNL} = \text{A-level} + 12$$

AIRCRAFT NOISE DESCRIPTORS

In study of airport and aircraft noise, two different types of noise measures are needed -- one to measure the noise of *individual noise events*, such as the noise signal of an aircraft flyover, and another to describe the *noise environment* resulting from a complex of noise events, such as the noise exposure due to aircraft operations at an air base.

The noise exposure forecast (NEF) value is a measure of the *noise environment*. But, it is necessarily based upon noise descriptions of individual noise events, such as an aircraft flyby or a ground engine runup.

Effective Perceived Noise Level and Sound Exposure Level

Both the A-level and PNL (or PNLT) can be used to measure the maximum level of an aircraft flyby or engine runup. But neither measure takes into account the duration or the noise event, and laboratory tests show clearly that the *noisiness* and *annoyance* increase with the signal duration as well as magnitude.

Several measures have been devised to account for both the magnitude and the duration of noise.

The effective perceived noise level (EPNL) takes the duration of the signal into account by integration of the noise level with time for the duration of the event. This is illustrated in the upper part of Figure 6. The noise measure which is integrated is the tone-corrected perceived noise level (PNLT). The signal duration is defined as the period during which the noise signal is within a prescribed number of decibels of the maximum noise level. Thus for an aircraft flyover, the signal duration would be on the order of several seconds to perhaps half a minute, depending primarily upon the distance between the aircraft and the observer. For a ground runup the signal duration may vary from a few seconds to many minutes.

In a similar manner, the A-level can be integrated with time over the noise event, as illustrated in the lower part of Figure 6. The resulting noise measure is the "sound exposure level" (SEL).

The exact relationship between the EPNL and SEL will vary with details of the noise event, but like A-level and PNL, will be well correlated for many aircraft sounds, with the EPNL, typically, 2 to 9 dB greater in magnitude than the SEL value.

The upper and middle sections of Figure 7 summarize two of the noise measures for single events discussed so far -- the A-level and PNLT, and the EPNL and SEL.

A tone correction, similar to that used with PNLT, the tone-corrected perceived noise level, can be added to the A-level, to obtain the tone-corrected A-level, ALT. Integration of the ALT with time, then yields the tone-corrected sound exposure level, SELT.

Noise Exposure Forecast, Day/Night Level

A description of aircraft noise in terms of the maximum noise levels for individual noise intrusions is helpful in comparing one aircraft with another or relating the aircraft noise to other sources of noise in the community.

However, we must still construct an environmental descriptor to express the subjective response to a variety of noise intrusions throughout a period of time. It was recognized quite early that such descriptors should make allowance not only for the annoyance of a single event but also for the number of events and the time of day of these events. Most environmental descriptors of aircraft noise in use in the world today are based on this principle. One starts out with a single event descriptor. A correction factor is applied for the number of aircraft noise events that occur during a given period of the day. Similarily each of these periods is given

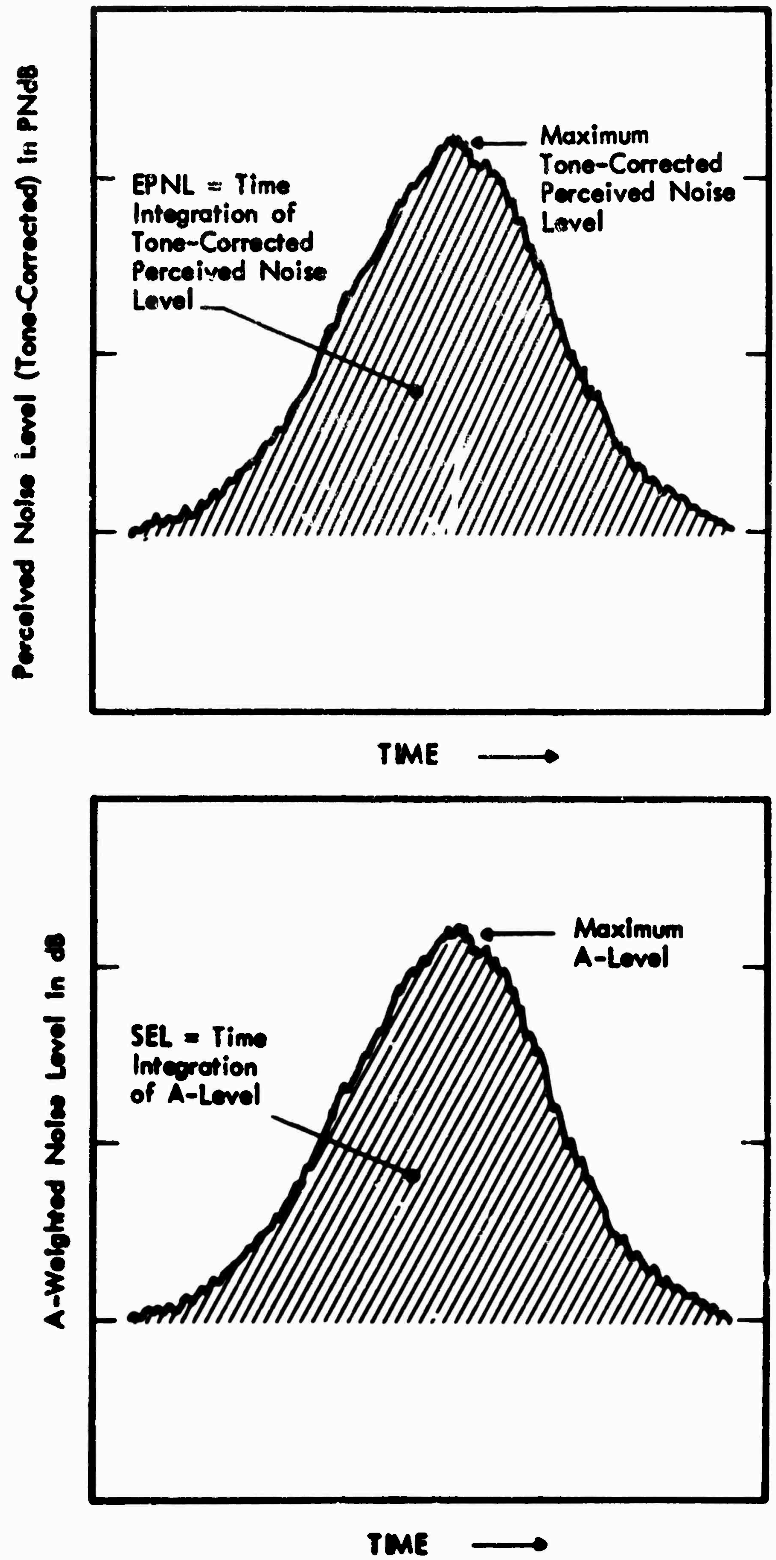
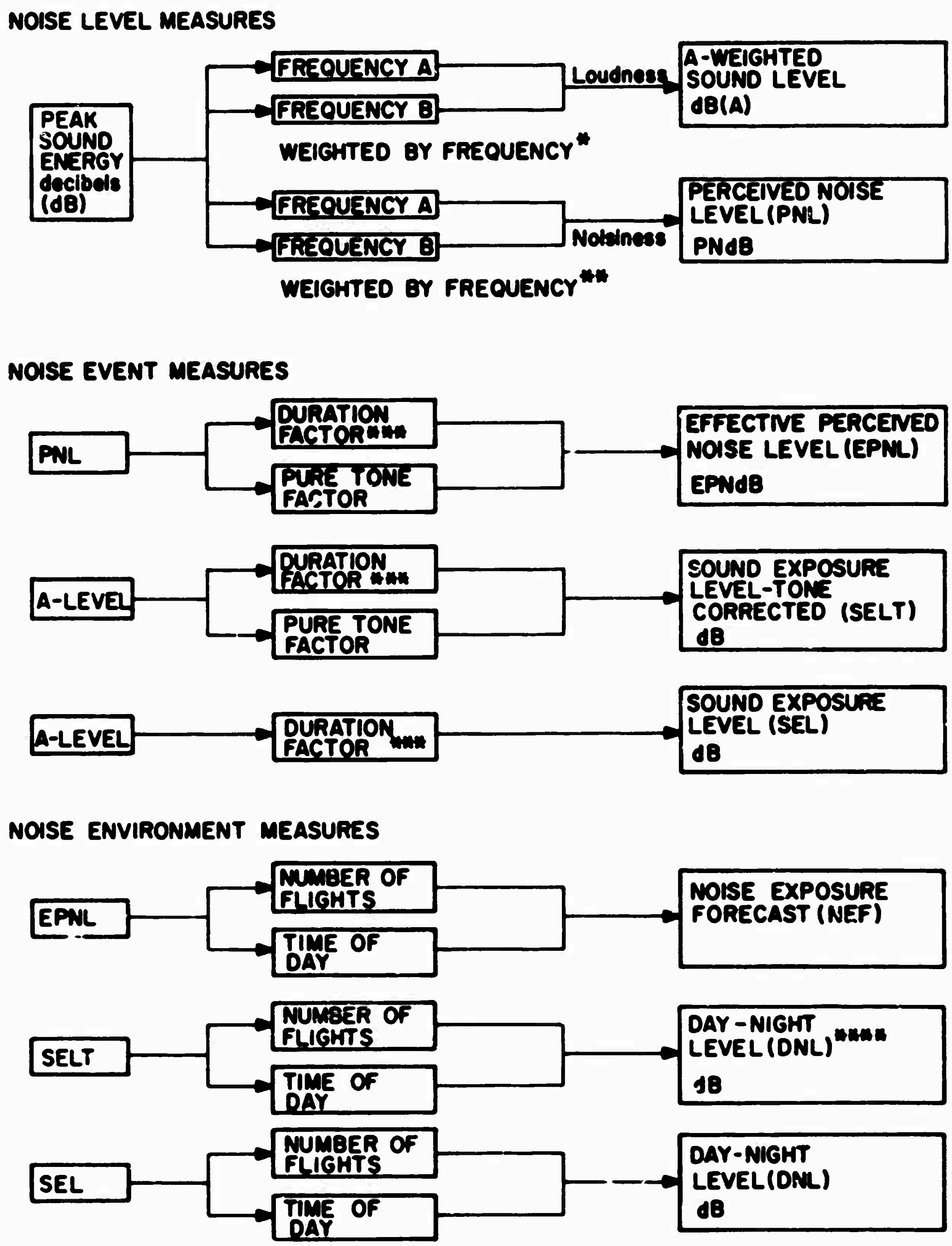


FIGURE 6. COMPARISON OF NOISE MEASURES FOR SINGLE EVENTS



*A simple frequency equalization network

**Analysis in 1/3 or full octave frequency bands

***Time-integration of signal

****Includes Pure Tone Factor

FIGURE 7. COMPARISONS OF AIRCRAFT NOISE MEASURES

a weight depending on the time of day. Since these descriptors are concerned with the environment for residential areas, nighttime events are considered more annoying than daytime events and thus nighttime noise events count heavier than similar events during the day.

The composite noise rating (CNR) which has been in use by the Department of Defense is one of these measures[1*]. It was based upon the PNL and contained provision for accounting for the number of aircraft operations and the time of day. The method had several shortcomings: it was based on the PNL with no correction for duration of flight events or for the presence of "pure tones"; adjustments for the number of events, or for adding together the noise contributions of different classes of aircraft, was on a "step" basis that occasionally led to unrealistic and inaccurate noise exposure estimates.

The noise exposure forecast (NEF) concept and accompanying calculation procedures remedies many of the shortcomings of the CNR. The NEF is based upon the effective perceived noise level and therefore contains corrections to account for pure tones and for duration. Also provision is made to account for noise from all operations and not just the noisiest ones. The next chapter will discuss the NEF in greater depth.

Other descriptors are in use in the United States. The Environmental Protection Agency (EPA) has introduced an environmental measure, called the day/night level (DNL)[2], based on the SEL noise event measure rather than the EPNL. In terms of application to aircraft situations, it is based on the same considerations as the NEF, and, indeed, except for changes in noise data base and a few constants, the computer programs used to calculate NEF contours can be utilized to generate DNL contours.

It is anticipated that the EPA will encourage the widespread use of DNL in describing airport noise environments throughout the country. In anticipation of such widespread use, the Air Force aircraft noise data is processed so that AL, ALT, SEL, and SELT data are available as well as PNL and EPNL data.

In summary, the lower portion of Figure 7 shows the major considerations involved in calculation of the NEF and DNL measures.

AIRCRAFT NOISE SOURCES

The aircraft noise sources of major interest are the turbojet and turbofan engines. Although many piston and turboprop aircraft are flying, their contribution to the noise environment is generally small *when* jet aircraft also operate.

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*References are listed together at the end of this report.

Turbojets and Turbofans

Turbojet and turbofan engines are in general much larger in terms of power output and produce considerably more noise than turboprop or piston engines. For example, a single military turbojet engine, in afterburner, may generate in excess of 70 kilowatts of acoustic energy, as compared to less than a milliwatt for a human voice. Besides producing higher overall levels, jet engines may produce more noise in the higher frequencies, which causes the noise to be more annoying.

There are two major sources of noise in the jet engine: the roar of the jet exhaust; and the turbomachinery, compressor and fan noise from turbulence produced by rotating blades in the engine. The upper portion of Figure 8 shows the location of sources of noise in a modern turbofan engine.

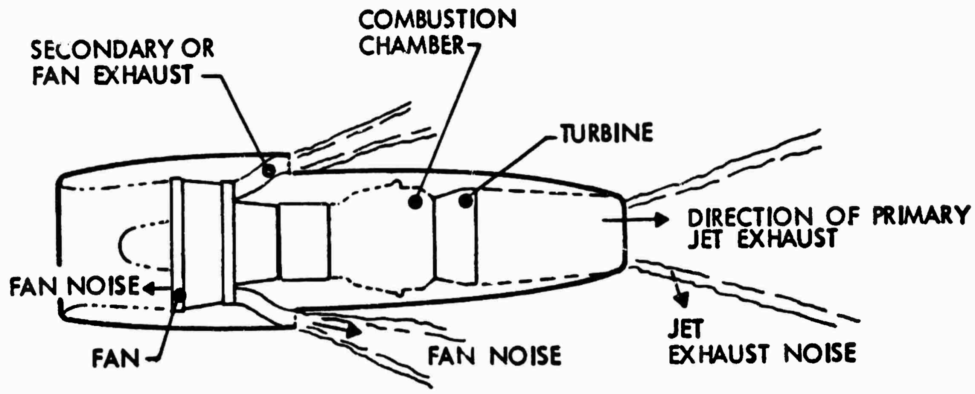
The exhaust noise is generated by the expansion of the high-velocity exhaust stream into a quiet atmosphere. The shearing forces involved in this process will produce a turbulent eddy system that produces the noise. The scale of the turbulence (the size of the eddies) is small close to the engine and increases downstream. Since the frequency of the noise is inversely proportional to the eddy size, the high and low contributions to the jet noise are generated in different parts of the exhaust wake behind the engine.

The amount of noise generated by a given air jet is roughly proportional to the eighth power of the jet velocity. Put in different terms, a doubling of the exhaust velocity corresponds to a 256-fold increase in acoustic energy, or, in terms of decibels, an increase of about 25 dB. In-flight noise suppressors therefore aim to reduce the average jet velocity in the exhaust stream by inducing air from the surrounding atmosphere into the jet stream.

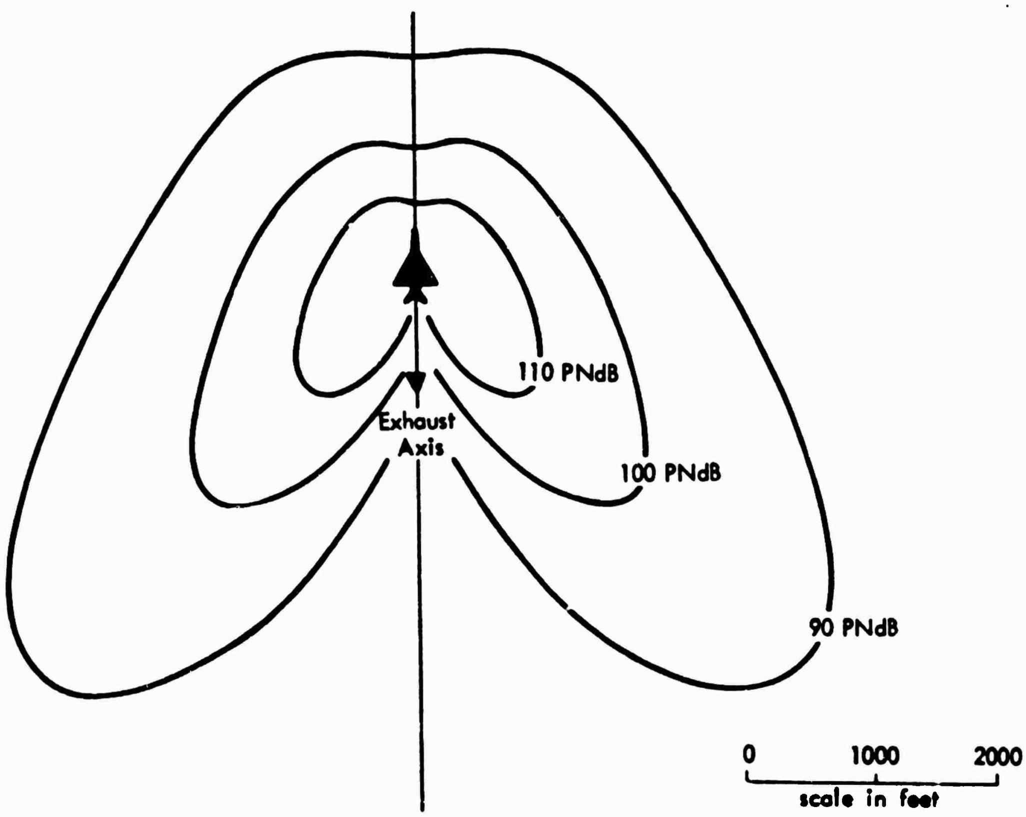
The turbofan engine produces much less noise for the same engine power for precisely this same reason. The outer portion of the engine, the fan duct, produces a secondary air flow around the primary jet exhaust reducing the shearing gradients between the jet core and the atmosphere. This principle is carried out to a high degree in the high-bypass ratio engines of modern large transport aircraft. These engines are attractive because they produce more usable power output for a given amount of fuel in addition to their quiet operation.

The use of afterburners in military aircraft accomplishes, from an acoustic point of view, exactly the opposite as the fan jet. Here the velocity of the exhaust jet is increased, thereby increasing the noise output.

For jet exhaust noise, the angle of maximum reduction is of the order of 30 to 50 degrees relative to the exhaust axis. For this reason, the maximum noise level found on the ground will occur



A. MAJOR NOISE SOURCES IN A TURBOFAN ENGINE



B. TYPICAL DIRECTIVITY PATTERN FOR A LOW BYPASS RATIO TURBOFAN ENGINE RUNUP

FIGURE 8. TURBOFAN ENGINE NOISE SOURCES AND DIRECTIVITY PATTERN

well after the aircraft has passed overhead, when the rear "lobe" of the noise pattern reaches the observer. The lower portion of Figure 8 depicts a typical directivity pattern for a turbofan aircraft at takeoff power.

Engine noise sources, other than the exhaust noise, typically are easily recognizable and even dominant during approach and taxi operations. The characteristic whines of compressors and fans may be extremely annoying.

In the newer civil versions of the high bypass turbofan engines, major steps are taken to reduce fan noise. Reduction in noise is accomplished by elimination of inlet guide vanes, slowing the fan speed, and lining the nacelle ducts with acoustically absorbing material.

Propeller Aircraft

For either the piston or turbine-powered propeller aircraft, the propeller is usually the predominant noise source at takeoff power settings. Although noise is generated over a wide range of frequencies the main contribution is at the lower frequencies. Most energy is radiated around the propeller blade passing frequency (1/60th of the engine rpm times the number of blades), and multiples of this frequency.

Engine exhaust noise is also an important noise source for the piston-aircraft, hence, at takeoff power, a turboprop aircraft will usually be quieter than a comparable piston-powered plane. At idling or taxiing power, however, the turboprop engine shares with other jet engines the high-pitched whine of the compressor.

SOUND PROPAGATION

The propagation of noise from a source to a receiver depends on several factors such as their relative distance, atmospheric conditions and intervening acoustic barriers. The influence of distance is a very simple one. As the noise spreads out over a larger and larger area the amount of energy per unit area becomes less and less. This decrease in intensity is inversely proportional to the square of the distance between source and receiver, or put in terms of decibels, the level will decrease by 6 dB for each doubling of distance.

There are several atmospheric effects that influence the propagation of sound. A very important factor is absorption due to water vapor in the air. The higher the frequency of the sound the more strongly will it be absorbed in the air. We are all familiar with this phenomenon: thunder propagated over a long distance sounds like a low grumble, whereas when the lightning strikes close by there is much high-frequency crackling. Similarily one can hear the drums of a marching band from a great distance; as they get closer more and more of the other instruments become audible.

The two dashed curves in the upper part of Figure 9 illustrate the increased absorption of high-frequency sound energy: the high-frequency curve decreases with distance much more rapidly than the mid-frequency sound curve.

In developing PNL and EPNL curves for use in calculating NEF values, the effects of air observation are taken into account, assuming a standard day (59°F, 70% relative humidity). Predictions based on such temperature and humidity conditions provide conservative estimates for a wide range of weather conditions. However, special noise curves can be generated, when needed, for any desired temperature and humidity.

The lower portion of Figure 9 shows two typical perceived noise level curves. Two cases are shown -- one for the takeoff of a turbojet fighter and one for the takeoff of a turbofan transport. Note that, in comparison with the curves in the upper part of the figure, the curves change in shape with distance, reflecting the actual aircraft frequency spectrum, and the varying amounts of high and low frequency sound energy present.

For aircraft in flight, and when the line of sight between observer and aircraft is greater than about 10 degrees above the horizon, air absorption effects are typically the most important propagation influence. For propagation at lower angles to the ground, or propagation over ground (from an engine test stand, for example) other propagation factors may become important.

Temperature gradients in the air may influence the propagation. During periods of "normal" temperature gradients (i.e., the air gets cooler as one gets higher) the sound tends to be deflected upward, causing "shadow zones" at certain distances from the source. Conversely during periods of "temperature inversion" the sound tends to be curved downwards tending to increase sound levels observed on the ground.

Wind conditions also affect sound propagation. The sound tends to bend upwards into the wind and downwards in the downwind direction. These atmospheric effects are, however, by no means steady. The inhomogeneity of the atmosphere complicates the problem even further. The result is that although the basic principles are understood the actual quantitative prediction leaves much to be desired. Measurements in the open atmosphere of the sound level due to a constant source may fluctuate as much as 10 or 20 dB when the distance is a few thousand feet.

Sound propagation very close to the ground has its own set of additional variables. At low angles of observation there is a "ground effect" due to ground surface reflections and absorption that tends to decrease the noise levels observed below what one would expect on the basis of free field estimates. It is also intuitively clear that intervening hills, buildings, etc., will have a decided impact on the propagation of sound.

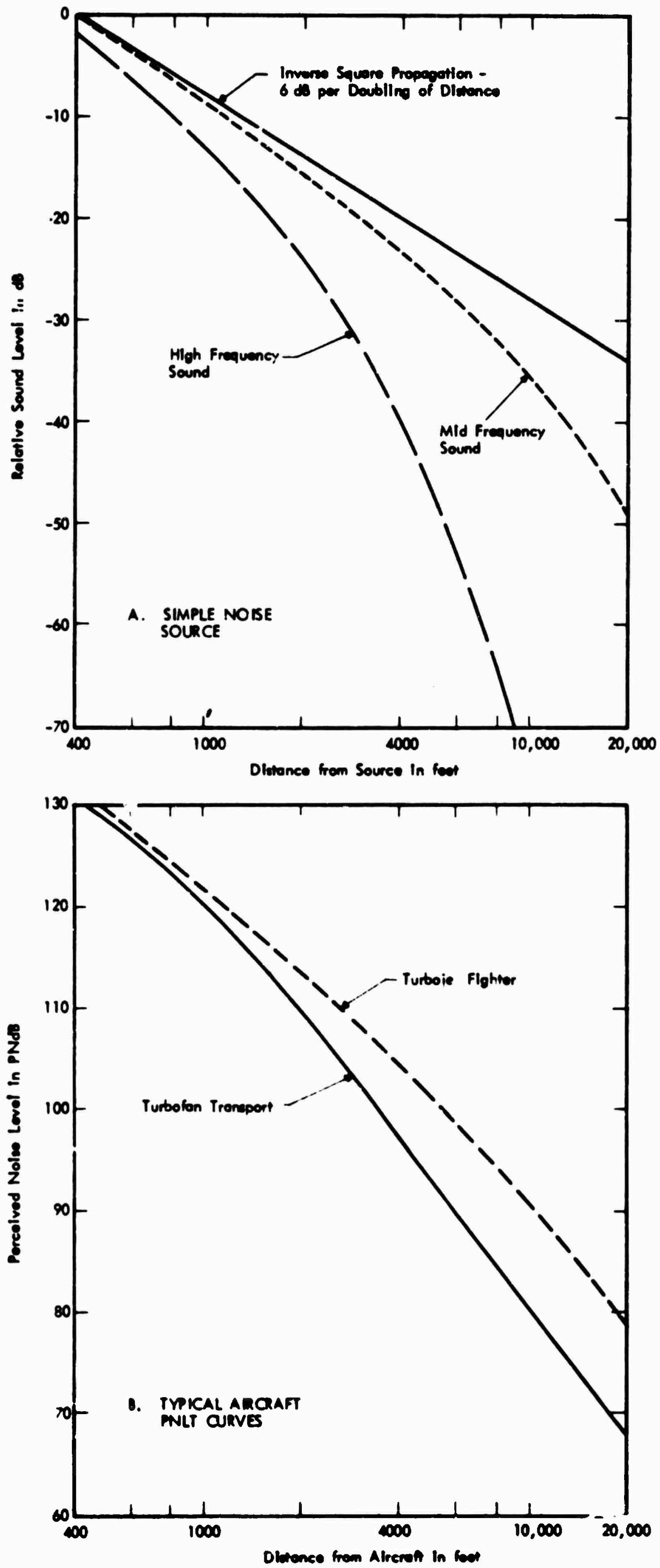


FIGURE 9. TYPICAL SOUND PROPAGATION CURVES

The Air Force data file provides noise curves for both air-to-ground and ground-to-ground propagation and the computer program automatically chooses the appropriate curve (and necessary transition adjustments) based upon consideration of the angle of the aircraft above the horizon as seen at the ground observer location.

NOISE CONTROL MEASURES

Noise Control measures are always concerned with a modification of the source, a modification of the path between source and receiver, or a modification of the receiver. Noise control at the source, although the most desirable method, is often not achievable. We have seen earlier how the use of high bypass turbofans can result in a reduction of the jet noise on takeoff. Certain modifications, such as lining engine nacelles with acoustically absorptive material, will make often a significant reduction in the noise produced at landing power. Compressor whine and other engine related noise can be reduced in this fashion. Research continues in engine design, but the development of quieter engines is a slow and arduous task. Often a great advancement in technology is required before a physical principle can be applied in a safe and reliable production engine.

Modification of the path from source to receiver would involve the use of barriers, natural or artificial, to interrupt the line of sight between aircraft and observer. Such shielding is practically restricted to locations close to airfields which are exposed to noise from ground operations. Sometimes a community is effectively shielded from an airport by hills, but many artificial barriers have limited effectiveness. The shielding barrier must be long and tall compared to the source, it must be located close to the noise source, and its geometry must be carefully chosen. A barrier must interrupt the "acoustic line of sight"; a single row of trees that may interrupt the line of sight is acoustically worthless. A large area of densely planted tall trees is required before such vegetation has any acoustic effect.

The most important path modification to consider in most airport situations is the noise attenuation provided by a building housing the observer. Most structures provide a moderate degree of noise attenuation, and it is possible, although often not practical nor economically feasible, to provide a very high degree of noise attenuation in a structure. And, of course, requiring people to alter their lifestyle to spend a larger portion of their life indoors may not be a socially acceptable solution. Section V provides more information on the potentials and limitations of building noise attenuation as a noise control tool.

The control of noise as discussed above is concerned with decreasing the noise from a single event. Noise impact as defined by an environmental descriptor such as the NEF can also be reduced in other ways: reducing the number of noise intrusions, reducing the duration of the noise intrusions, or by transferring some or all of the nighttime activity to the daytime hours. This aspect is further discussed in Section VI.

SECTION III

DESCRIPTION OF NEF PROCEDURES

The noise exposure forecast (NEF) was introduced in Section II as an environmental descriptor of aircraft noise. As such it takes into account not only the annoyance due to the individual noise event, but the contribution from the multiple noise events occurring during a 24-hour period.

The basic single event descriptor for the NEF is the effective perceived noise level (EPNL). As described in Section II the EPNL contains all the refinements that are considered necessary in assessing one's subjective reaction to an individual aircraft noise event:

- the *noisiness* of the signal noise spectrum
- a correction for the pressure of *audible pure tones*
- an adjustment for the *duration* of the event

To get from this basic EPNL information to the NEF, several steps are necessary. Conceptually, one must provide:

- a means for accounting for the cumulative effect of many operations by differing types of noise sources
- a weighting factor to account for the variation in community response to aircraft noise depending on the time of day
- a weighting factor to account for the increased sensitivity in residential areas to noise from ground runup operations in contrast to flight operations.

Then, to have a useful description, one must relate the NEF values to the expected impact of noise on people, on communities and on land areas.

Finally, to proceed from concepts to a working tool, one must acquire a data base of aircraft noise and performance information, and develop a means for computing and displaying the NEF contours (or numbers).

BASIC NEF EQUATIONS

In the discussion of Section II it was mentioned that the human auditory perception behaves more or less logarithmically, resulting in the decibel scale. This same behavior is also applicable to the frequency of occurrence noise events. Thus, in the NEF procedure, the same dependence is used as for the decibel scale, namely ten times the logarithm to the base 10 of the number of operations. Thus, a doubling in the number of like noise intrusions results in an increase of 3 dB in the NEF value.

The twenty-four hour day is broken into day (0701-2200) and night (2201-0700) periods, and a penalty assigned for night operations. This nighttime adjustment is chosen so that for the same number of operations *per hour* the nighttime contribution is 10 dB higher than during the day*. The resulting expression for noise events of the same magnitude is:

$$NEF = EPNL + 10 \log_{10} (N_D + 16.67 N_N) - 88 \qquad (1)$$

where:

N_D = number of day events

N_N = number of night events

The "constant" of -88 appearing in Equation (1) arises from two considerations:

- it is desirable that the NEF value be distinctly different in magnitude from the EPNL so that there would be little likelihood in confusing effective perceived noise levels with NEF values.
- it is desirable that a "zero" or very small NEF value indicate noise exposure that would have no impact on even the most sensitive land uses or activities.

Equation (1) yields the NEF for a specified uniform set of operations -- ground runups or a specific type of engine at one power setting and duration at a given location, flight operations of one class of aircraft along one flight path, etc. The total NEF at a given ground position is determined by the summation of all the NEF contributors on an "energy" basis. Formally, then:

$$NEF = 10 \log_{10} \sum^{i} \text{antilog} \frac{NEF_i}{10} \qquad (2)$$

Summing over all noise events that contribute to the noise environment at the location.

Note that the summation of NEF values is exactly the same as the addition of decibels, explained in Section II. Hence the rules given in Figure 2 may also be used for adding NEF values. Figures to be presented later in Section VI also may aid in estimating NEF values, once EPNL values are determined.

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*This results in a multiplicative constant of 16.67 for nighttime operations, as given in Equation 1, when one accounts for the differing number of hours in the day and night periods.

Figure 10 presents an example of NEF computations involving the aircraft operations. Working through the example will convince one of the desirability of computerizing the calculations where NEF values are desired for an array of ground positions.

INPUT INFORMATION

Aircraft Data

To be effective as a tool, the data necessary to estimate noise levels at any ground position must be assumed in a form for ready access in calculation. For flight operations, aircraft noise information, obtained from controlled flight tests, is analyzed to obtain EPNL versus distance curves for different takeoff and landing thrust conditions. Figure 11 shows a typical set of EPNL curves. The figure also shows the corresponding PNLT curves for the aircraft. Note that the EPNL curves differ from the PNLT curves since the EPNL curves reflect the signal duration, while the PNLT curves do not.

The computer program allows for adjustments in the EPNL curves for intermediate power settings, for variation in aircraft speed (which would influence duration) and duration adjustments for curved flight paths.

Separate EPNL curves are provided to account for ground (or low-angle) propagation. And, the program provides adjustments to automatically account for aircraft acceleration during ground roll during takeoff.

In order to predict the EPNL value at a given observer location for a particular aircraft operation one must determine the relative location of aircraft and observer and compute the distance between the aircraft and observer. One can define the aircraft motion in terms of a flighttrack and an altitude profile. The flighttrack is the projection onto the ground plane of the three dimensional flight path of the aircraft. The altitude profile is the performance characteristics of the aircraft in terms of altitude versus distance from start of takeoff roll.

The altitude profile information for basic aircraft missions is stored in the computer program for each major type of aircraft. Special profiles, reflecting special missions, or particular base air traffic restrictions may readily be entered, also.

Flighttrack information is entered by transferring track data from maps showing flight paths. Alternatively, for departures, the computer program will develop flight tracks from standard air traffic departure instructions. To aid in this task, typical turn radii are stored for each type of aircraft.

Consider a ground location, where information on flight tracks, number of operations and EPNL values for each aircraft type and flight track is known, as follows:

Aircraft Type	Flight Track	EPNL	Number of Day Operations	Number of Night Operations
A	1	90	30	4
B	1	95	2	1
C	2	98	5	1

The steps below summarize the calculations for the first aircraft listed above.

1. Find the effective number of operations by multiplying the number of night operations by 16.67 and adding the product to the number of day operations.

Number of night operations (4)	
x 16.67 =	66.68
+ number of day operations	30.00
= weighted number of operations	96.68

2. Determine the total adjustment for number of operations by taking 10 times the logarithm of the effective number of operations.

$$10 \log 96.68 = 19.85$$

3. Add the EPNL value for the aircraft and flight track.

$$19.85 + 90 = 109.85$$

4. Subtract the constant, 88, to obtain the NEF contribution for the aircraft.

$$109.85 - 88 = 21.85$$

Calculations for the three aircraft are summarized as:

Aircraft	EPNL	Movements Day	Movements Night	Weighted Number (N)	10 log N	EPNL + 10 log N-88
A	90	30	4	96.68	19.85	21.85
B	95	2	1	18.67	12.71	19.71
C	98	5	1	21.67	13.36	23.36

Finally, the NEF contributions are added on an energy basis to obtain the total NEF.

$$\text{NEF(total)} = 10 \log \left[\text{antilog} \frac{21.85}{10} + \text{antilog} \frac{19.71}{10} + \text{antilog} \frac{23.36}{10}\right]$$

$$= 10 \log [153.1 + 93.5 + 216.8] = 10 \log 463.4 = 26.7$$

(NOTE: Figure 2 could also be used to add the quantities)

FIGURE 10. EXAMPLE OF NEF CALCULATIONS FOR ONE GROUND POSITION

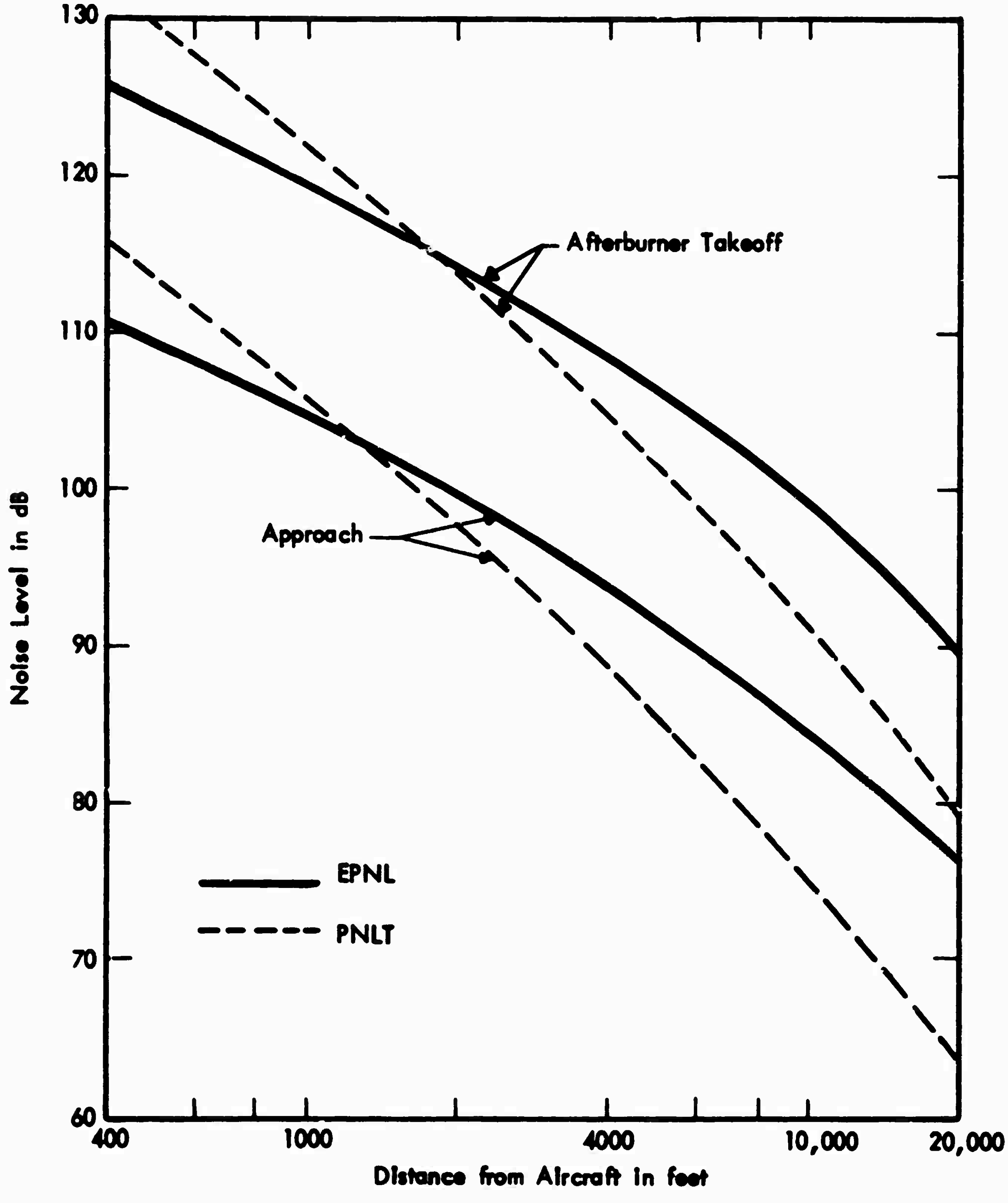

FIGURE 11. REPRESENTATIVE EPNL VS DISTANCE CURVES FOR A TURBOJET FIGHTER AIRCRAFT

Engine Runups

Basic noise information for engine runups on ground (engine test stands, line maintenance runs, etc.) is based upon noise measurements made at constant radius about an engine, for several different engine power settings ranging from idle to full military or afterburner. Curves are computed from the measured data at different angles to give the variation of the tone-corrected perceived noise level (PNLT) with distance. Like the airborne data, air absorption for standard day conditions is assumed, plus additional attenuation representative of typical terrain effects. Sets of these curves are stored in the computer, together with rules for interpolation between curves, so that noise levels may be predicted for any angle and distance from the engine.

EPNL values are calculated from the PNLT values and the duration of the engine run of a particular power setting. Figure 19, discussed in Section VI, can be used to estimate NEF values for runups of a given duration and number of occurrences.

Air Base Data

Basic aircraft and engine data, as described above is called from the computer storage as needed for a particular air base. Data on the operations at an air base is acquired from the individual bases, utilizing the detailed questionnaire forms and requests given in Appendix A. The needed data includes detailed information on flight track, departures and landing procedures, number of operations, location of engine test runup stands, etc. It is vital that this information be accurate and representative if accurate NEF contours are to be drawn!

NEF CONTOUR EXAMPLE

Figures 12 presents an example of NEF contours for an air base. The upper portion of the figure shows the NEF contours for only ground runup operations (line maintenance and test stand operations, etc.), while the lower portion shows the NEF contours for *combined* air and ground operations. It is easily seen that, in this example, the air operations are controlling in most areas around the base.

This air base has only a single runway, with takeoffs and landings switched in direction depending upon the wind. Both IFR and VFR practice landing patterns account for much of the complexity of flight tracks and resulting noise contours.

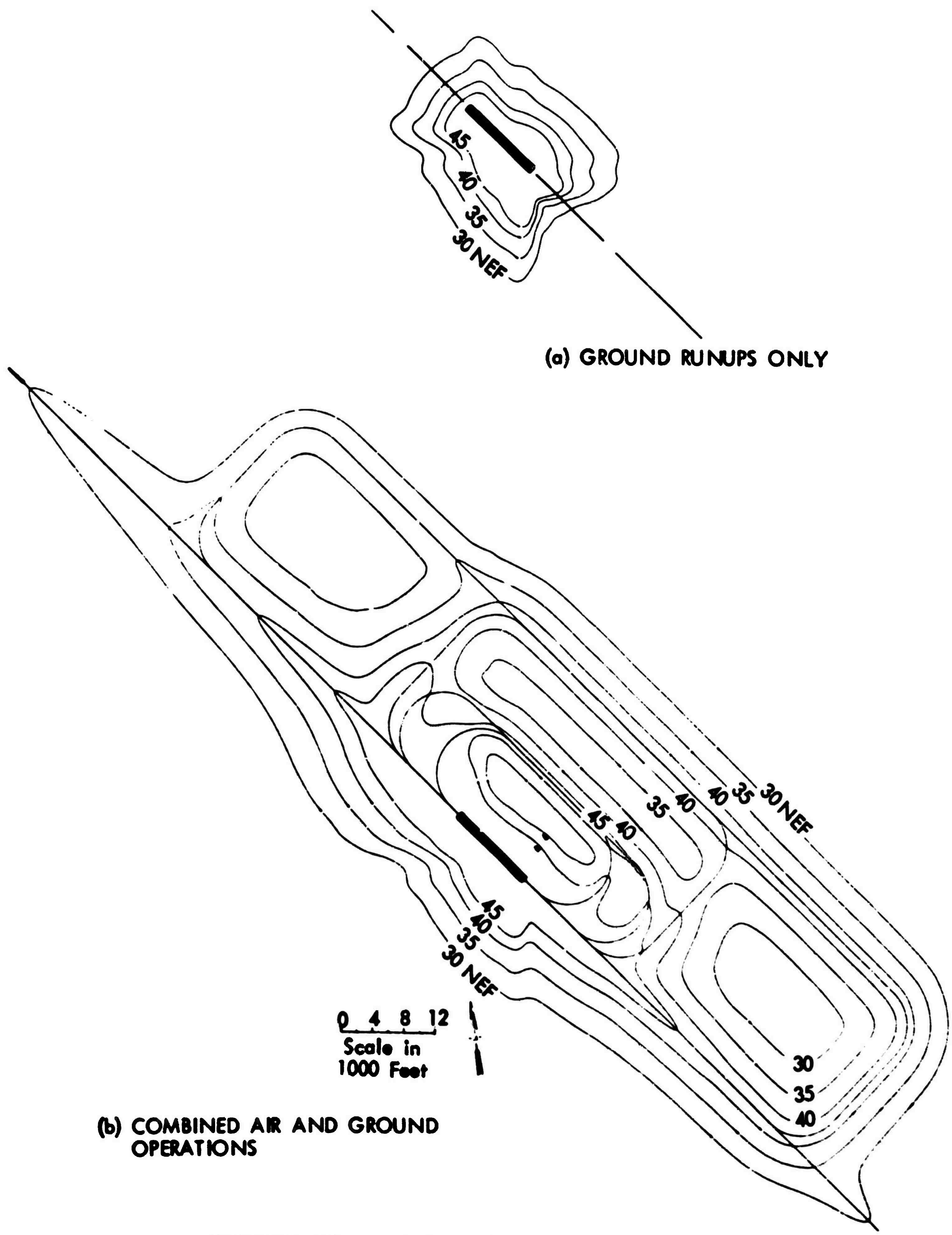

FIGURE 12. AIR BASE NEF CONTOURS

NEF CONTOUR ACCURACY

As in any prediction calculation, the accuracy of the NEF contour is heavily dependent upon the accuracy of the input data, which, as seen above, comes from a number of sources -- some data are stored in the computer, other data come from the air base questionnaires.

The stored data describes, basically, the aircraft noise and performance. Variability and error is introduced by the variability in sound propagation due to changes in weather conditions, and the variability in duplication of aircraft profiles. Weather, of course, affects aircraft performance as well as sound propagation. In addition, there is variability in pilot techniques, and, of course, variations in aircraft profiles and engine settings due to aircraft weight differences. All of these factors are manifested as vertical and horizontal dispersion in the flight paths.

NEF contours are typically based on the averages of operation over a year period, although, where there are large seasonal variations in operations, NEF contours can be developed for representative seasons. In either case, one averages over a period of time, and operations on individual days may show quite large departures from the average operations. Appendix B briefly reviews the impact of such variability in planning for noise monitoring to verify predicted noise levels.

The three largest sources of error in air base operational data are, typically: flight track information, the relative number of operations using specified flight paths or air traffic procedures, and the number and duration of ground runups.

Flight track information is likely to decrease in accuracy with distance from the air base. Errors arise, again from variability in pilot techniques, weather, aircraft weights, and lack of ground confirmation of actual flight paths flown. This last may be remedied by direct observation by ground observers, or monitoring of air traffic radars. Such monitoring will often disclose wide variability in flight tracks among aircraft flying the same missions.

Errors in estimating the relative usage of flight paths usually arises from the lack of accurate records, since, in the past, there was little or no need for such information. Records are kept, of course, of total number of flight operations. Here, errors may arise in averaging over an insufficient, or non-representative, time period.

Errors in estimating NEF values for ground engine runups often arise from lack of records as to the number and duration of runups, since these records have rarely been kept in detail.

Because of the many factors affecting sound propagation over the ground, the noise levels measured at large distances from engine test stand, are likely to show larger variations than for the aircraft-in-flight to ground case. Because of this variability and the possible influence of local terrain features upon noise propagation, sizeable errors in predicted noise levels at large distances (over 10,000 feet) can occur.

The variables and possible sources of error are not a flaw in the NEF procedures; any other environmental descriptor will be influenced by the same factors. Because of the many sources of variability, the accuracy of the NEF contours will typically be highest near the runways, and will gradually decrease with distance from the runway, or major flight paths.

When accurate data on aircraft performance, weather, and position are available, one can expect to predict EPNL values, over reasonable weather limits, to within a standard deviation of plus or minus one to two dB up to slant distances of the order of 10,000 feet. Where the performance, position, and weather information is only nominally known, the standard deviations increase to as much as ± 4 dB. Field measurement experience indicates that cumulative noise exposure from a number of events seems to be predictable to about one-half the variation in prediction of EPNL alone. Thus, it is reasonable to assume that with reliable input data, one can predict actual noise exposure with a standard deviation of about ± 2 units of NEF.

SECTION IV

LAND USE AND COMMUNITY RESPONSE INTERPRETATIONS

Much of the usefulness of the NEF contours lies in their interpretation in terms of effects on people. In this section, interpretations are given in two contexts. First, NEF values are interpreted in terms of impact on land uses. These guides are directed towards aiding land planning and development within air bases and in community areas outside air base boundaries. Next, an interpretation of NEF values is given in terms of expected community response. This information is given as a guide for assessing the probable degree of response to noise in community areas, or for assessing the changes in community response resulting from a change in the noise environment.

The input of aircraft noise may be characterized generally in terms of several areas of interest:

1. Effects on people as individuals.
2. Effects on community actions and attitudes.
3. Impact on human activities (work and recreational) and land uses.

The effects of noise on people and people's activities are varied and often extremely complex. Thus, in relating noise exposure to impact on people, information has been drawn from a large number of experiments and observations. These include controlled laboratory psychological and physiological tests, case history studies of community reactions to aircraft noise, and both small and large scale social surveys.

The effects of noise may be grouped into three interrelated aspects:

1. *Physiological effects,* both temporary (e.g., startle reactions and temporary hearing threshold shifts), and enduring (for example, permanent hearing damage or the cumulative physiological effects of prolonged sleep loss).
2. *Behavioral effects* involving interference with ongoing activities such as speech, learning, T.V. watching, sleep or the performance of work tasks.
3. *Subjective effects* described by such words as "annoyance", "nuisance", "dissatisfaction", "disturbance" which result as a result of behavioral and physiological effects.

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Generally, the levels and durations of aircraft noise encountered away from the immediate vicinity of runway and maintenance areas are not severe enough to produce easily measurable long-term physiological effects. For example, the noise levels produced by aircraft flyovers at community positions even close to the runways are not intense enough to cause permanent loss of hearing. Thus, the last two categories of noise effects -- behavioral and subjective -- provide the most usable guides for establishing aircraft noise criteria. Particularly useful information comes from studies of the effects of noise on speech communication and sleep, information gained from case history studies of community response and social surveys in a variety of airport community situations.

There is considerable variability in sensitivity among individuals. There is also considerable variation in the social and economic composition of different communities and in the interests of communities in air base activities. Thus, the guides given in this section predict "typical responses" or attitudes quite well, but will not necessarily predict accurately the behavior of any one individual or the response of any given segment of a community. Prediction accuracy could be improved by using detailed social and economic information about a community, for example. However, such detailed information is rarely available for planning purposes.

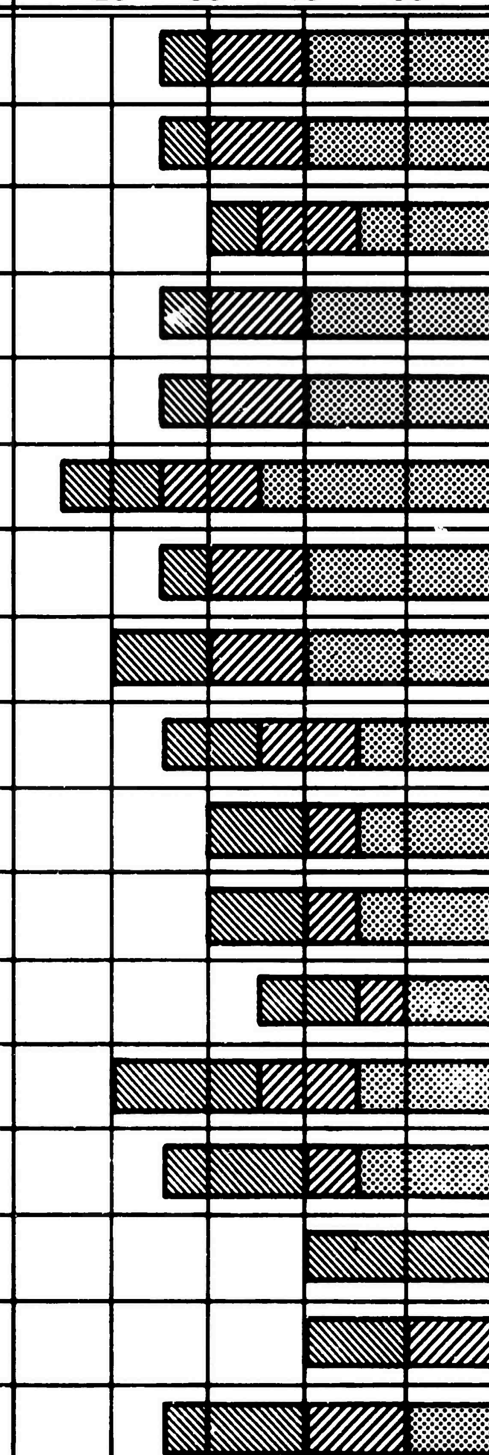
LAND USE INTERPRETATIONS

Figure 13 provides compatibility interpretations of NEF values for major land use categories. The figure shows four noise compatibility interpretations for each land use. These four compatibility interpretations are defined in terms of suitability for construction as used in Department of Housing and Urban Development's "Noise Assessment Guidelines".[3] The four zones range from "clearly acceptable" to "clearly unacceptable".

Figure 13 also gives a "noise sensitivity code rating" which provides a gross ranking of the land use in terms of noise sensitivity. The number 1 indicates the land uses most sensitive to noise and 5 the land uses that are least sensitive. The approximate relationship between the noise sensitivity code and the NEF level at which new construction or development is not desirable is given below.

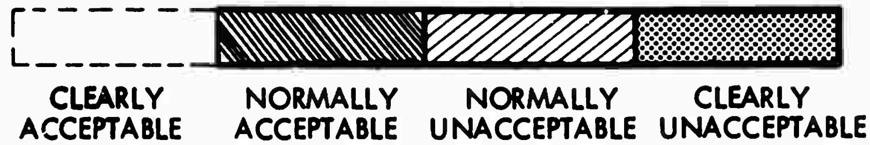
Noise Sensitivity Code	Approximate Noise Exposure Forecast Value Where New Construction or Development is Not Desirable
1	30
2	35
3	40
4	45
5	50 to 55

LAND USE CATEGORY	SLUCM[1] CODE	NSC[2]	LAND USE INTERPRETATION FOR NEF VALUE * (20 30 40 50)
Residential-Single Family, Duplex, Mobile Homes	11x[3]	1	
Residential-Multiple Family, Dormitories, etc.	11x, 12, 13, 19	1	
Transient Lodging	15	2	
School Classrooms, Libraries, Churches	68 7111	1	
Hospitals, Nursing Homes	651	1	
Auditoriums, Concert Halls, Music Shells	721	1	
Sports Arenas, Outdoor Spectator Sports	722	1	
Playgrounds, Neighborhood Parks	761, 762	1	
Golf Courses, Riding Stables, Water Rec., Cemeteries	741x, 743x, 744	2	
Office Buildings, Personal, Business and Professional	61, 62, 63, 69, 65[4]	3	
Commercial-Retail, Movie Theaters, Restaurants	53, 54, 56, 57, 59	3	
Commercial-Wholesale, Some Retail, Ind., Mfg., Util.	51, 52, 64, 2, 3, 4	4	
Manufacturing, Communication (Noise Sensitive)	35, 47	2	
Livestock Farming, Animal Breeding	815, 816, 817	3	
Agriculture (except Livestock), Mining, Fishing	81, 82, 83, 84, 85, 91, 93	5	
Public Right-of-Way	45	5	
Extensive Natural Recreation Areas	91, 92, 93, 99, 7491, 75	3	



* DNL ≈ NEF VALUE + 35

FIGURE 13-A. LAND USE COMPATIBILITY GUIDELINES FOR AIRCRAFT NOISE ENVIRONMENTS



CLEARLY ACCEPTABLE:

The noise exposure is such that the activities associated with the land use may be carried out with essentially no interference from aircraft noise. (Residential areas: both indoor and outdoor noise environments are pleasant.)

NORMALLY ACCEPTABLE:

The noise exposure is great enough to be of some concern, but common building constructions will make the indoor environment acceptable, even for sleeping quarters.
(Residential areas: the outdoor environment will be reasonably pleasant for recreation and play.)

NORMALLY UNACCEPTABLE:

The noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure adequate performance of activities.
(Residential areas: barriers must be erected between the site and prominent noise sources to make the outdoor environment tolerable.)

CLEARLY UNACCEPTABLE:

The noise exposure at the site is so severe that construction costs to make the indoor environment acceptable for performance of activities would be prohibitive.
(Residential areas: the outdoor environment would be intolerable for normal residential use.)

[1] Standard Land Use Coding Manual (Ref. 4)

[3] Noise Sensitivity Code

[3] x represents SLUCM category broader or narrower than, but generally inclusive of, the category described

[4] Excluding hospitals

FIGURE 13-B. NOTES FOR LAND USE COMPATIBILITY GUIDELINES FOR AIRCRAFT NOISE ENVIRONMENTS

The interpretations given in Figure 13 are based on considerations of many different noise sensitivity factors. These factors include:

1. Speech communication needs.
2. Subjective judgments of noise acceptability and relative noisiness.
3. Need for freedom from noise intrusions.
4. Sleep sensitivity criteria.
5. Case histories of noise complaint experience near civil and military airports.
6. Typical noise insulation provided by common types of building construction.

The land use guides of Figure 13 are based upon the types of building construction that would normally be used where aircraft noise is no concern. Added noise attenuation can be provided in structures, often at moderate costs in new construction, but, typically, at relatively high costs for modification of existing construction. The capability to provide additional noise attenuation instructions provides great flexibility in locating office and industrial activities, but has quite limited usefulness as a means for relaxing compatibility requirements for residential construction (see Section V).

Figure 13 indicates a range of NEF values for each compatibility zone. When it is necessary to establish a land use boundary within a zone, the following should be considered:

1. *Previous community experience.* Taking into consideration known response or complaint history in previously developed areas which are exposed to similar NEF values may aid in selection of NEF descriptor boundaries within the limits indicated in Figure 13.
2. *Local building construction,* particularly as influenced by climate considerations. In northern portions of the country, wall and roof constructions may be slightly heavier and houses are likely to be more tightly constructed, thus reducing the extent of noise leakage paths. In addition, windows would typically be kept closed for a larger portion of the year, and less use would be made of outdoor areas. On this basis, one might select a higher NEF value as the boundary for a noise compatibility interpretation, rather than a lower NEF value range that might be suitable for a warmer climate.
3. *Existing noise environment* due to other urban or transportation noise sources. For NEF values greater than about 30, the influence of other transportation or urban noise sources is likely to be quite small. However, for NEF values less than 30, noise due to other

sources may temper the response or consideration of restrictions on land use. For example, introduction of aircraft noise in a rural or semirural area where existing background noise levels are very low may produce a much more apparent change in the noise environment and more pronounced reactions from residents than would aircraft noise introduced in a dense urban area long exposed to traffic noise. Such considerations may make adjustments of the noise compatibility interpretation boundaries appropriate in specific local situations.

4. *Time period of land use activities.* Typically, NEF contours are based upon considerations of both day and night operations, with a weighting for night operations. This is particularly appropriate for residential land use considerations, but may lead to overestimation of NEF values for work activities or land uses that are confined to daytime hours only.

COMMUNITY RESPONSE INTERPRETATIONS

The degree and, indeed, the kinds of community response to aircraft noise are influenced by many community factors in addition to the physical noise environment itself. Thus the guides given in this section to predicting community response are just that, guides, not absolute predictors. Examples can be found of individual community actions that depart in either direction from the guides given in this section.

From recent studies it is known that a number of nonacoustic influences may effect an individual's response to noise. Some of the influences include:

1. Fear of aircraft crashing in the neighborhood.
2. Susceptibility to noise in general.
3. Extent to which airport and air transportation are seen as important.
4. Belief in misfeasance by those able to do something about the noise problem.
5. Extent to which other things are disliked in the environment and belief about the effect of noise on general health.

Similarily in terms of communities, the degree of community response will certainly be influenced by such factors as:

1. The degree of economic and social ties between the community and the air base.

2. Feelings within the community as to the necessity of the operations causing the noise intrusion.

3. Past history of results in handling other community/ air base problems.

The following chart relates NEF values to anticipated response in residential communities. Three broad categories of community response are correlated with NEF values.

Chart for Estimating Response of Residential Communities

Noise Exposure Forecast	Description of Expected Response
Less than 30	Essentially few complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
30 to 40	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 40	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

An additional guide in predicting the appropriate percent of people likely to be annoyed, or to complain[2], is given in Figure 14. This shows the percent of highly annoyed as a function of the NEF value. It is worth noting that this curve indicates that there would be essentially no annoyance due to aircraft noise exposure for NEF values of 22 or less. Also, the figure indicates that a 10 dB change in the noise exposure would result in about a 20% change in the percent of people highly annoyed.

The interpretation given above and in Figure 14 can be used in two different ways. First of all, the guides can be used as a predictor, say, for an entirely new situation for which one has little information about the community or response to previous exposure. This application would arise in planning for a new air base, or, perhaps, a new community.

A second way to use the guides, with NEF information, is in assessing possible response in a community to charges in noise exposure. In this application, one may use as a base line the already known complaint history for the community, and use Figure 14 to estimate the expected change in community response. This provides a means for obtaining a "calibration," based on existing community attitudes, which should reflect existing community and air base relationships.

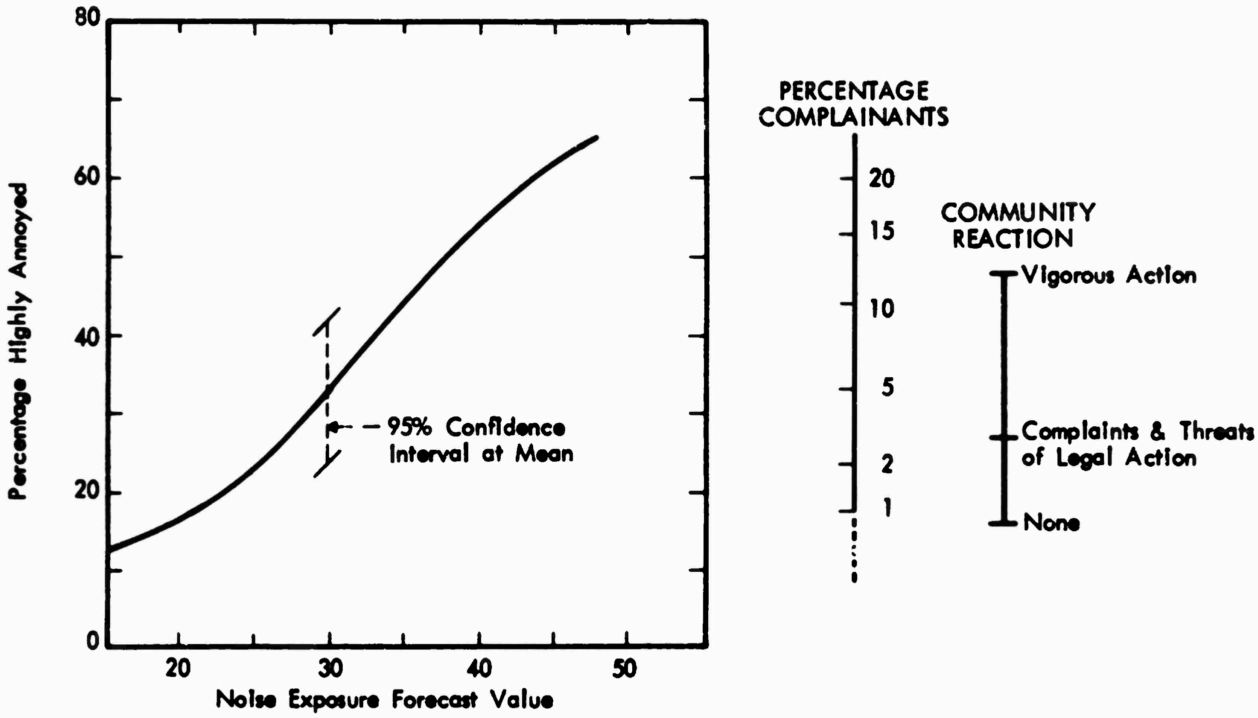


FIGURE 14. COMPARISON OF INDIVIDUAL ANNOYANCE AND COMMUNITY REACTION AS A FUNCTION OF NOISE EXPOSURE FORECAST VALUES

SECTION V

NEF LAND PLANNING APPLICATIONS

This section outlines some of the direct applications of the NEF to land use planning. The NEF procedures provide a tool to define noise impact in a qualitative manner. However, effective land use planning requires much effort, even when useful technical tools are available. Major problems are encountered in terms of lack of enabling legislation to accomplish effective planning over large areas, lack of joint action by the multiple local jurisdictions impacted by operations from a single airport. Legal responsibilities and liabilities are often ill-defined and, of course, the economic costs may be formidable.

In the past, land use policies and planning if developed in detail at all was done largely at a local governmental level. The results of such haphazard planning has long been obvious and has greatly retarded rational air base planning and development. However, a number of states have enacted or introduced legislation encouraging or enforcing planning on a regional or area basis. It is probable that federal legislation will soon be enacted that will encourage or make mandatory regional planning to a much wider extent. The concept of regional or area planning provides greater opportunities for sensible land development around airports. It also greatly increases the responsibilities of air base planners and need for closer air base interaction with regional agencies.

Of course, noise is only one of the many environmental factors that must be considered in land planning. In this respect, NEF contours can be used with quantitative evaluations of other environmental factors in arriving at the complex assessments needed for effective planning.

MAPPING NOISE CONFLICT AREAS

Once NEF contours have been developed, various noise conflict areas may be identified by overlay of noise contours over suitable maps drawn to a similar scale. Figure 15 shows the conceptual application in geographic identification of noise conflict areas. In this example, noise sensitivity zones are defined in terms of NEF values. Overlay of the NEF contours provides direct identification of conflict areas.

From such mapping, one may quantify noise conflicts by identifying the number or area of specific land uses that are not compatible. This should be done for sensitive land uses: residential areas, schools, churches, libraries and public buildings.

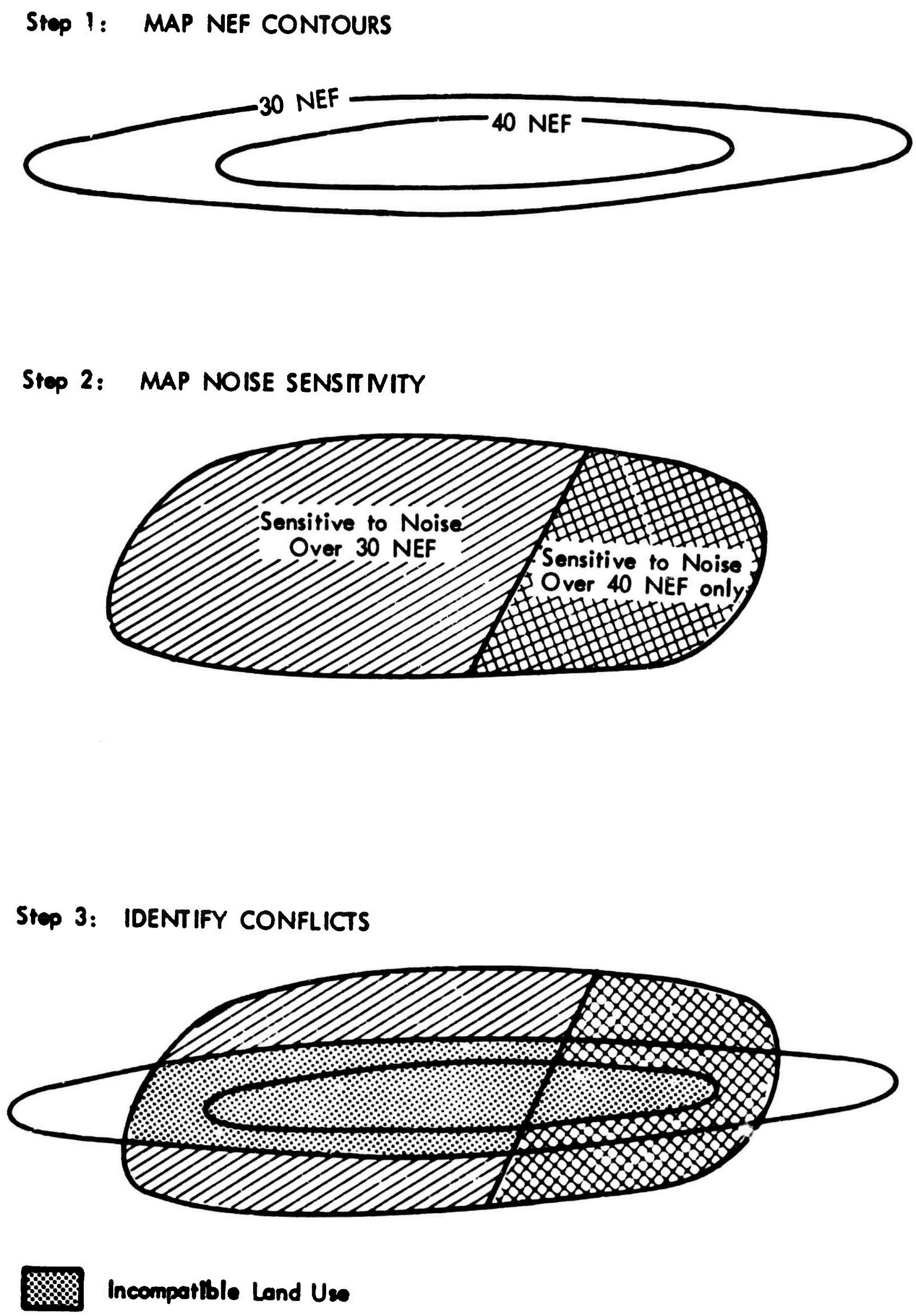


FIGURE 15. IDENTIFYING NOISE CONFLICT AREAS

Quantization of residential noise conflict areas may be in terms of gross areas, or preferable, in terms of number of housing units or number of residents, with the choice determined, to a large part, by the kind of land use information that is available for the particular community.

For any but the smallest bases, initial identification of noise conflict areas may be done by using C&GS 7½ minute quadrangle maps drawn to a scale of one inch to 2,000 ft. (1 = 24,000).

Unfortunately, the C&GS maps are often out of date, hence recent air base and community developments are frequently not shown. Current population and land use information is obviously essential. Local and regional planning agencies should be contacted for help in obtaining up-to-date information.

In a similar manner, the NEF contours can be overlaid zoning maps, population density maps, and surface transportation maps (present and projected) to determine types and extent of conflicts.

The NEF contours may be used in conjunction with maps defining other environmental factors, or with air space height restriction, or accident zone maps. From comparison of such overlays, various "Compatible Use Districts" may be defined[5]. Regardless of the degree of detail to which comparisons can be carried out, the comparison of NEF contours with existing and projected noise sensitive land uses is a *basic step* in defining noise conflicts in a quantitative manner.

LAND USE STRATEGIES

Strategies for achieving land use compatibility as a means of reducing noise conflicts always involve some degree of control or regulation, direct of indirect, of land use. The economic costs, and the legal, political and administrative difficulties in achieving the necessary control of land use is a major limitation in the application of such strategies. Despite these obvious problems, the various strategies available should be explored carefully for applicability to each individual air base. Opportunities for applying effective land use strategies frequently occur, particularly with regard to land not already developed.

The major land use strategies include the following:

1. Land use purchase or lease.
2. Land use easements.
3. Land use zoning and building code restrictions.
4. Land use reconversion or relocation.
5. Encouragement of compatible development.
6. Subdivision regulation.

7. Public service planning (transportation facilities, recreational areas, etc.).

The usefulness of these strategies is greatly dependent upon the degree to which land is already developed. For undeveloped areas the range of tools will be much wider and less costly to apply than in already developed areas. From review of the above strategies it will be apparent that most will require active and close liaison with the local and regional agencies responsible for land planning and development in areas around the airport.

The remainder of this section will discuss applications of NEF contours to land zoning and to establishing building noise insulation requirements. Before discussing these applications, one must note that it is difficult to legally justify the drawing of boundary lines or zones for application of particular policies for frequently changing aircraft operating procedures and widely variable flight paths. Implementation of any land use strategy based on noise level contours will generally require standardization of flight patterns and a policy of maintaining these patterns to maintain near uniform noise impact patterns over a period of time. Changes in operations and in noise exposure will, and must, occur as missions and weapons change, but frequent, erratic or sudden major changes in the noise environment (and resulting NEF contours) can drastically undermine land use strategies. Such problems arising from major changes in the noise environment increases the need for early assessment of the environment characteristics and noise impact of new weapons systems (see Section VII for further discussion).

The needs for realistic assessments of the noise environment, and to periodically check the validity of noise environment predictions underlie the growing interest in airport noise monitoring systems. Monitoring systems can be viewed as an aid to planning and operations, with the monitoring information serving as a means of evaluating the combined effect on the noise environment of varied changes in airport operations -- whether due to changes in missions, aircraft, or flight procedures.

NOISE ZONING

Zoning is the placing of legal restrictions on permissible uses of private property with the general intent of preventing conflicts between land uses. Zoning has usually been exclusively a local governmental responsibility with its legal foundation in the power to regulate for the general health, safety, and welfare. In zoning, one may set up a scale of uses and densities and allow uses lower on the scale to take place in areas zoned higher on the scale. It is primarily a *preventative policy* and has little value in already developed areas. Zoning, as traditionally used, can provide three functions:

1. Preserve existing compatible land uses.
2. Prevent changes to compatible land uses.
3. Lead to compatible uses where no dominant use has yet been established.

Zoning based on consideration of noise exposure is a relatively new approach to land use compatibility that has yet to be applied on a wide scale. It has been proposed primarily for civil airports and for relatively undeveloped areas, and has a particularly strong potential in the development of any new airport or air base. Such zoning, to be effective, must be adopted in near similar form by all the zoning agencies within the noise impact area. Legislation has recently been passed in several states to encourage or make mandatory joint planning and zoning actions to accommodate major new airports.

A typical approach combines noise zoning and building noise insulation requirements to provide the needed flexibility in land use controls. As an example, recent planning for a major new airport defines five land use zones, with zone boundaries based upon projected NEF values[5]. Figure 16 lists major land uses, the NEF ranges of each zone and the restrictions in usage.* For some uses, land uses are permitted in a zone of greater noise exposure providing the buildings meet minimum noise insulation requirements, specified in terms of a minimum reduction of outside aircraft noise levels (referred to as "*noise level reduction*" or NLR).

Building code amendments spell out the structural requirements. These requirements can be achieved by adopting certain specific materials and design features in the construction, or, to provide more flexibility, other construction features may be adopted if the plans can be certified by a professional acoustician that the noise level reduction requirements will be met. A test procedure is provided for use where building officials believe that field verification of NLR values is needed.

The approach described clearly shows the ties between zoning and the establishment of minimum building noise reduction requirements. Without specifying minimum requirements on building noise insulation, much more rigid, and restrictive, land use allocations would be necessary.

BUILDING NOISE LEVEL REDUCTION REQUIREMENTS

Noise insulation can be a very useful tool for reducing noise impact areas in non-residential areas and for work activities which largely

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*The land use restrictions shown in Figure 16 have been developed for a particular area -- more restrictive limits on some land uses may better fit community needs elsewhere.

ACTIVITIES AND LAND USES	SLUCM CODE*	LAND USE NOISE ZONES				
		GREATER THAN 40 NEF	35 TO 40 NEF	30 TO 35 NEF	25 TO 30 NEF	LESS THAN 25 NEF
Residential** (single family)	11 x (10), 14	Not Allowed	Not Allowed	Permitted with NLR 25	Permitted	Permitted
Residential** (multi-family), Educational and Institutional	11 x, 12, 13, 19, 68, 7111, 651	Not Allowed	Permitted with NLR 30	Permitted with NLR 25	Permitted	Permitted
Auditoriums, Concert Halls	721 x	Not Allowed	Not Allowed	Permitted with NLR 35	Permitted with NLR 30	Permitted
Outdoor Amphitheaters, Music Shells	7[illegible]1 x	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Permitted
Offices, Personal, Business and Professional Services, Commercial-Retail, Movie Theaters, Restaurants	61, [illegible], [illegible], [illegible], 65 (11)	Permitted with NLR 30	Permitted with NLR 25	Permitted	Permitted	Permitted
Transient Lodging-Hotels, Motels	15	Permitted with NLR 35	Permitted with NLR 30	Permitted with NLR 25	Permitted	Permitted
Sports Arenas, Outdoor Spectator Sports	722	Not Allowed	Not Allowed	Permitted	Permitted	Permitted
Playgrounds, Neighborhood Parks	761, 762	Not Allowed	Not Allowed	Permitted	Permitted	Permitted
Golf Courses, Driving Ranges, Water-Recreation, Cemeteries,	741 x, 743 x, 744	Permitted	Permitted	Permitted	Permitted	Permitted
Commercial-Wholesale and Selected Retail, Industrial/ Manufacturing, Transportation Communication and Utilities	2, 3, 4, 51, 52, 64	Permitted	Permitted	Permitted	Permitted	Permitted
Animal-related services	82 x	Not Allowed	Permitted	Permitted	Permitted	Permitted
Agricultural	81, 82 x	Permitted	Permitted	Permitted	Permitted	Permitted

*Reference 4
**It should be noted that areas above NEF 30 may not qualify for Federal funding in these construction categories according to HUD Circular 1390.2. Approval for funding may require noise attenuation measures, the Regional Administrator's concurrence and/or a 102(2)C environmental statement.

FIGURE 16. AIRPORT NOISE ZONING CHART SHOWING PERMITTED AND RESTRICTED LAND USES AND MINIMUM NOISE LEVEL REDUCTION REQUIREMENTS FOR STRUCTURES

take place indoors. And, as noted before, providing additional noise insulation in areas of high noise exposure greatly increases the flexibility in land use over that provided by a rigid interpretation of the land use criteria given in Figure 13. The drawbacks of added noise insulation is that it requires extra planning effort and results in additional construction costs. The degree of noise insulation that can be provided has practical cost limitations; generally, costs are considerably higher for modification of existing construction than for new construction.

While residential construction can be designed to meet high noise insulation requirements, the bulk of existing data indicates that noise insulation should be applied cautiously as a strategy for reducing noise impacts in residential areas. Three considerations warn against using improved noise insulation as a justification for relaxing aircraft noise -- land use compatibility interpretations based on usual residential construction:

1. The unlikelihood that improved noise insulation alone can significantly reduce the subjective impact of aircraft noise in residential areas.
2. The high cost of modification.
3. Practical difficulties in achieving high values of noise reduction with regular residential construction procedures.

Thus the major applications of improved noise insulation for improving compatibility with the noise environment should be to non-residential land uses.

Special noise insulation requirements have frequently been incorporated in buildings located near airports. The technical principles, the materials and the design requirements needed to produce buildings of improved noise insulation are well known.

Now, noise can be transmitted into a building either:

1. Directly, through openings such as cracks around windows or doors, water pipes, conduits or ventilation ducts, or other openings.
2. Indirectly, by the outdoor sound waves setting the building surfaces into vibration with the surfaces then re-radiating sound waves into the room. These surfaces can include any room surface; windows, doors, walls, roofs, even floors.

To control the noise levels inside the room, <u>both</u> kinds of noise paths -- direct opening and radiation of sound from building surfaces -- must be controlled. To achieve effective noise insulation, the noise energy contributions from all paths must be reduced significantly. Control of one path and neglect of others will typically result in inadequate noise insulation. One cannot compensate for a major weakness in one path (such as a window) by making other paths (walls and roofs, for example) better. Small exterior areas having poor noise insulation characteristics will drastically reduce the effectiveness of the remaining exterior surfaces.

Since noise insulation effectiveness is generally a function of the weight of the materials, one must often use heavier materials to replace lightweight ones -- thicker panes of glass, masonery instead of frame construction, dense concrete versus lightweight block or wood for example.

The weakest transmission paths are usually the windows and doors, hence these must be improved as the first step in obtaining improved noise insulation. Typically, windows must be improved by substituting heavier single panes, or even double panes, in frames with efficient gasketing to reduce leakage around the panes. Heavier doors, or even double doors, with efficient weatherstripping are also needed. With improved windows and doors, heavier walls and roofs may be needed, as well as design attention to such things as the noise transmitted through ventilation ducting or fireplaces, for example.

And, since direct openings to the exterior must be eliminated, mechanical air ventilation must be provided. For residential construction in most parts of the country, this means that an air conditioning system must be included as one step in improving the noise insulation.

Table I provides approximate noise level reduction values for some typical building constructions. Values are shown as ranges. Usually, the higher values would be observed near approach or landing paths or turbojet or turbofan aircraft. The lower values would be observed for propeller aircraft and for turbojet and turbofan takeoffs.

Estimating the NLR Requirements

The NEF contours, together with the compatibility guides of Figure 13 can be used to estimate the needed *improvement* in noise insulation for a building when it is to be placed in an adverse, normally noncompatible, noise environment. The detailed development of noise insulation requirements and actual construction needs must be established by more extensive engineering analyses.

The needed improvement in noise insulation can be estimated by taking the difference between the NEF value at the site, as interpolated from the NEF contours, and the "design" NEF extracted from Figure 13. The design value typically should be set by taking a value midway between the limits of the *normally acceptable* range. A more conservative "design" value might be chosen by taking the boundary between the *clearly acceptable* and *normally acceptable* ranges.

TABLE I

TYPICAL BUILDING CONSTRUCTION SOUND LEVEL REDUCTION VALUES

Type of Construction	Noise Level Reduction, dB*
Conventional lightweight - windows open	15 - 20
Conventional lightweight - windows closed	25 - 30
Conventional lightweight - no windows, or 1/4" glass windows sealed in place	30 - 35
1/8" glass windows, sealed in place	20 - 25
1/4" glass windows, sealed in place	25 - 30
Walls and roof - weighing 20 to 40 lbs/sq ft, no windows	35 - 40
Walls and roof - weighing 40 to 80 lbs/sq ft, no windows	40 - 45
Heavy walls and roof - weighing over 80 lbs/sq ft, no windows	45 - 50

*In terms of the difference between maximum levels measured outside and inside, expressed as either A-levels or perceived noise levels. The sound level reduction values apply, in general, to noise from aircraft and noise from most surface vehicles (autos, trucks, and motorcycles).

As an example, suppose an office building is proposed for a site where the NEF value is 45 dB. From Figure 13, the *normally acceptable* NEF range is from 30 to 40 dB. Taking 35 dB as the "design" value, there is a difference of 10 dB between site and "design" values. Hence, the building NLR should be improved by 10 dB over normal construction. Reference to Table I shows that for conventional lightweight construction, with windows closed, a NLR of 25 to 30 dB may be achieved. Thus, an actual NLR of 35 to 40 dB is needed.

Noise Insulation Costs

Analysis of noise insulation requirements, and actual field modifications of residential structures, show that improvements of up to 15 dB, to achieve total NLR values of 35 to 40 dB, are a practical limit for residential or light commercial construction. Greater noise attenuation can be achieved by special constructions, but costs rapidly increase.

To provide some indication of costs, Table II lists estimated costs for 5, 10 and 15 dB improvements in building attenuation for four types of buildings. Costs will, of course, vary with local building practices and costs. The Table II costs are for new construction; modification to existing buildings would be greater by percentages ranging from 10 to 50 percent.

TABLE II

APPROXIMATE COSTS FOR IMPROVED NOISE INSULATION IN NEW CONSTRUCTION*

Building Type	Improvement in NLR		
	5 dB	10 dB	15 dB
Single-Family Residence (1500 sq. ft.)	$4,000	$6,000	$7,000
Multi-Family Apartment (900 sq. ft.)	2,000	2,900	3,100
Motel Room (200 sq. ft.)	1,700	1,800	2,200
Office in Low-Rise Commercial Building (150 sq. ft.)	400	800	1,100

*For modification of existing construction, costs will usually be appreciably higher, by order of 10 to 50 percent.

SECTION VI

OPERATIONAL APPLICATIONS

The noise exposure forecast contours permit one to quantify the noise impact of changes in operations at an air base. Comparison of NEF contours before and after proposed changes in operations provides a direct visual means of assessing changes in noise impact. This is important because initial intuitive evaluations of proposed operation changes are often misleading.

For example, it may be relatively easy to visualize the changes in the noise contours (PNL or PNLT) for a possible change in aircraft operations. However, it is often very difficult to evaluate the overall effect of that change taking into account the noise impact of the remaining, unchanged air activity. The NEF procedures allow one to assess the combined effect; if desired, separate NEF contours can be developed for various classes of aircraft operations. By overlaying sets of contours, the relative contribution to the total noise impact may be directly evaluated.

The kinds of operational applications that can be evaluated by NEF procedures include:

1. Changes in volume and time of day of operations.
2. Changes in aircraft tracks and aircraft profiles.
3. Operational changes which may involve only a limited number of aircraft.
4. Determining relative contribution of ground runup and flight operations.
5. Changes in ground runup locations and engine or aircraft orientation at runup pads.

VOLUME OF OPERATIONS AND TIME OF OPERATIONS

In evaluating the impact of operational changes, one must keep in mind both the noise patterns of individual aircraft operations and the resultant impact from multiple operations, as evaluated by NEF's. It is important to recall that the NEF is dependent upon the *noise levels* produced by the different aircraft, the *number of operations* of each type of aircraft, and the *time of day* of the operations. To help visualize the tradeoff between the number of operations, noise level, and time of day, Figure 17 provides a graph for estimating the NEF value as a function of the number of operations per

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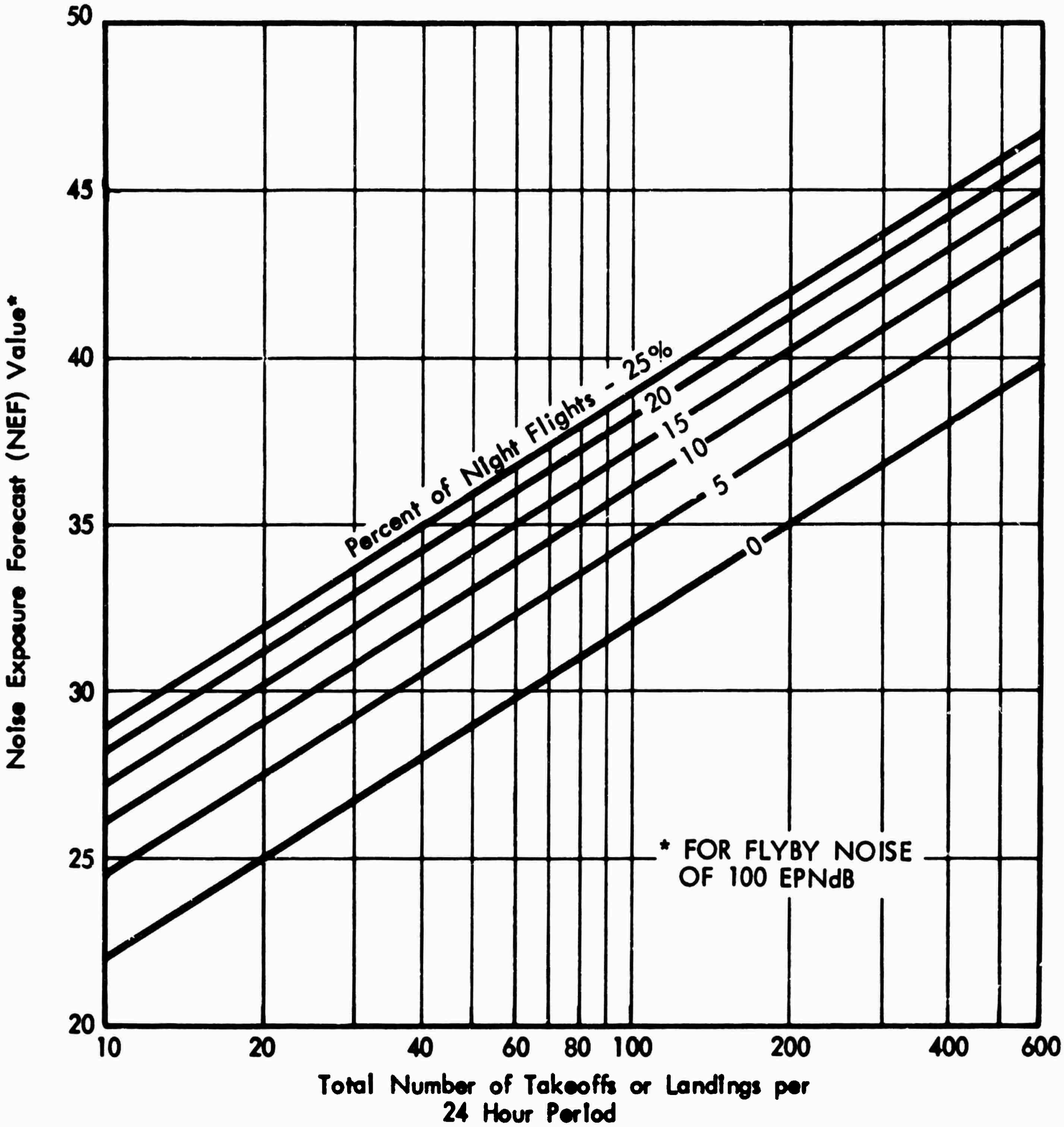


FIGURE 17. CHART FOR ESTIMATING NEF VALUES FOR FLIGHT OPERATIONS

24-hour day for a noise level of 100 EPNdB. Sets of curves are given for percentages of night operations varying from 0 to 25% of the total daily operations. The chart shows that for a fixed total number of daily operations, varying the percent of night operations from 0 to 25% increases the NEF value by approximately 7 dB. The chart also permits one to estimate the effect of the number of operations as well. Note that a *change in number of operations* from 10 to 20 results in the same *change in NEF values* (3 dB) as a change in operations from 100 to 200 per day.

Figure 17 may easily be used for noise levels other than 100 EPNdB by subtracting 100 from the noise level of concern, and adding this difference to the NEF value read from the chart.

Note that Figure 17 assumes all noise events are the same level. Where noise events are of different magnitude, Figure 17 should be used for each set of noise events of the same level, and the resulting "partial" NEF values added on an "energy" basis as previously explained (see Figure 8 for example).

GROUND RUNUP OPERATIONS

NEF contours for an air base include the combined effects of both airborne and ground runup operations (test stands, maintenance lines, etc.). If desired, separate NEF contours can be developed for only ground runup operations as shown in Figure 12.

Figure 18 may be of aid in evaluating the noise effects of changes in runup operations. This figure shows the NEF value for a perceived noise level of 100 dB produced by an engine runup as a function of the number of runups per day or per night period and the average duration of each runup. In the figure, the NEF for day operations is read directly. For nighttime runups, one must add 12.2 to the value obtained directly from the chart. This allows one to easily compare the relative impact of night and day operations. The total noise exposure forecast value may easily be obtained by adding (on an energy basis) the two NEF values, the daytime and nighttime NEF values, by using the chart from Figure 2.

Figure 18 reflects the fact that, in comparison to the equivalent noise exposure of a flight operation (taking into account maximum level and duration), the NEF contribution of a ground runup has an additional 10 dB weighting. This weighting stems from past case history experience at a number of airports where it was found that community acceptance of noise from known maintenance runups was much lower for a given noise exposure than for flyovers. Thus for an equal degree of community response, the case studies show that noise exposure from maintenance operations should be substantially lower than from flight operations.*

*This "penalty" for ground runup operations was also accounted for in the composite noise rating (CNR) procedures. In fact, in the CNR procedures, a greater penalty (approximately 15 dB) was placed on ground runup operations.

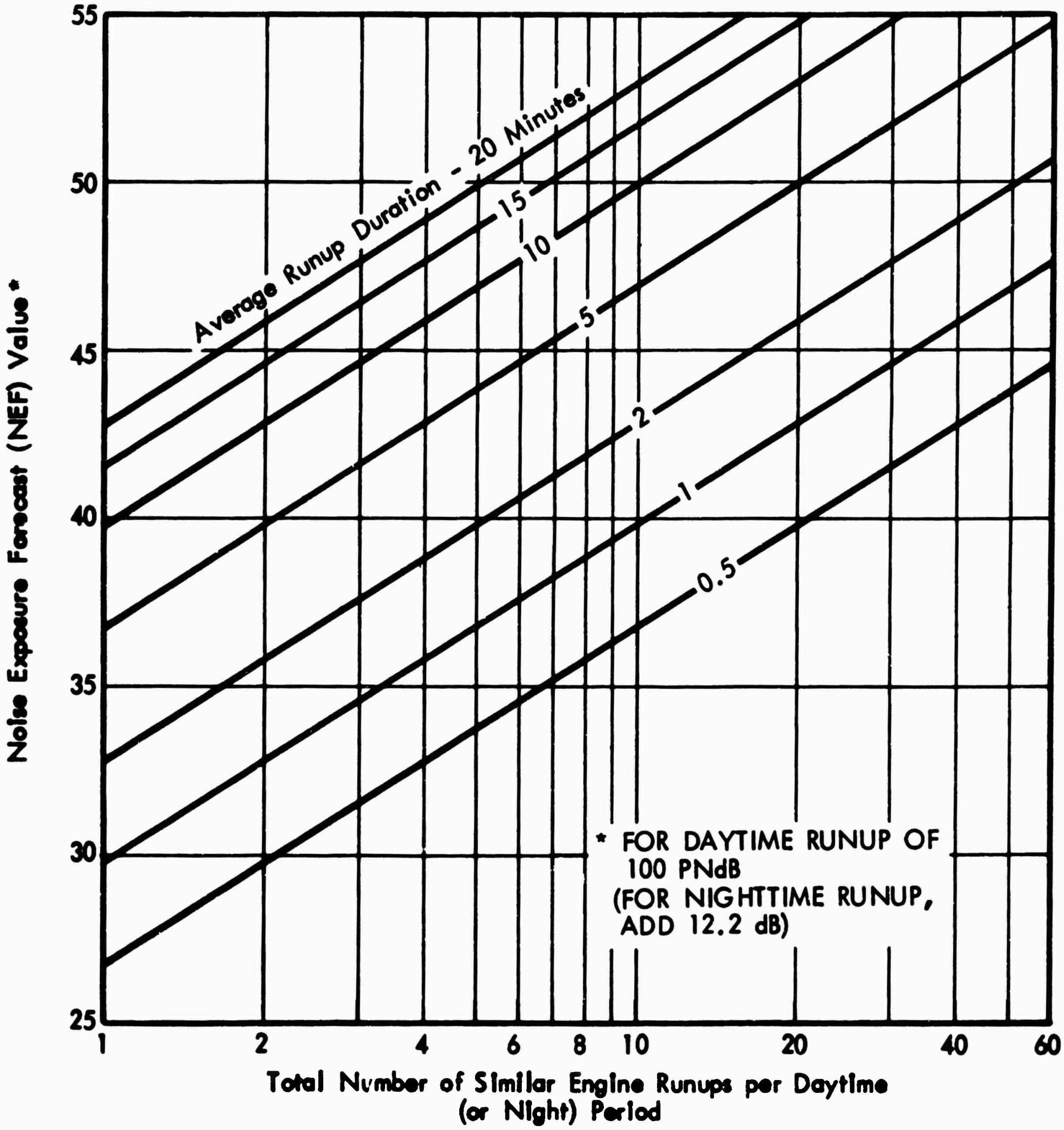


FIGURE 18. CHART FOR ESTIMATING NEF VALUES FOR ENGINE RUNUPS

For planning purposes, particularly where changes in existing ground runup locations are under consideration, the noise contours produced by single engine aircraft runups (similar to those shown in the lower portion of Figure 8) may be very helpful. Thus, both the PNLT noise contours and the NEF contours may be useful in studies to minimize noise exposure due to ground operations.

ENGINE NOISE SUPPRESSORS

Air bases may employ one or more types of noise suppressors to reduce the noise due to engine runups. The suppressors may vary greatly in effectiveness, varying from the totally enclosed test cell with acoustically lined intakes and exhausts, to the metal blast deflectors which are sometimes erroneously called suppressors. Intermediate between these are various types of noise suppressors which may provide some significant noise attenuation. To illustrate various degrees of noise suppressor effectiveness, Figure 19 shows PNL contours around an engine for three cases:

1. Open engine runup.
2. A deflector, which deflects the exhaust upwards, with little or no reduction in acoustic energy.
3. Enclosed engine in test cell with effective attenuation of intake and exhaust.

Note that the deflector may change the directional pattern, with reductions of noise in some directions and increases in others. With the test cell (lower portion of Figure 19) providing a net attenuation of about 20 dB, the resulting noise radiation pattern is nearly circular.

The NEF procedures will accommodate noise suppressor information. Thus, as noise suppressor data from field noise measurements becomes available, the NEF computer program will store and supply suppressor noise characteristics as needed.

FLIGHT PATH CHANGES

Flight path changes may involve changes in flight tracks over ground and/or changes in takeoff or descent profiles. For either type of change, the NEF contours provide a graphical means of evaluating the overall effect of such changes. PNL contours for individual aircraft operations will also be helpful.

To aid in reducing noise impact in adjacent community areas, such operational considerations as offset landing paths, variation in flight paths for IFR and VFR operations, and the introduction of alternate headings for departure aircraft can be studied. The possible benefits or drawbacks of altitude restrictions, or changes in landing pattern altitudes may also be investigated.

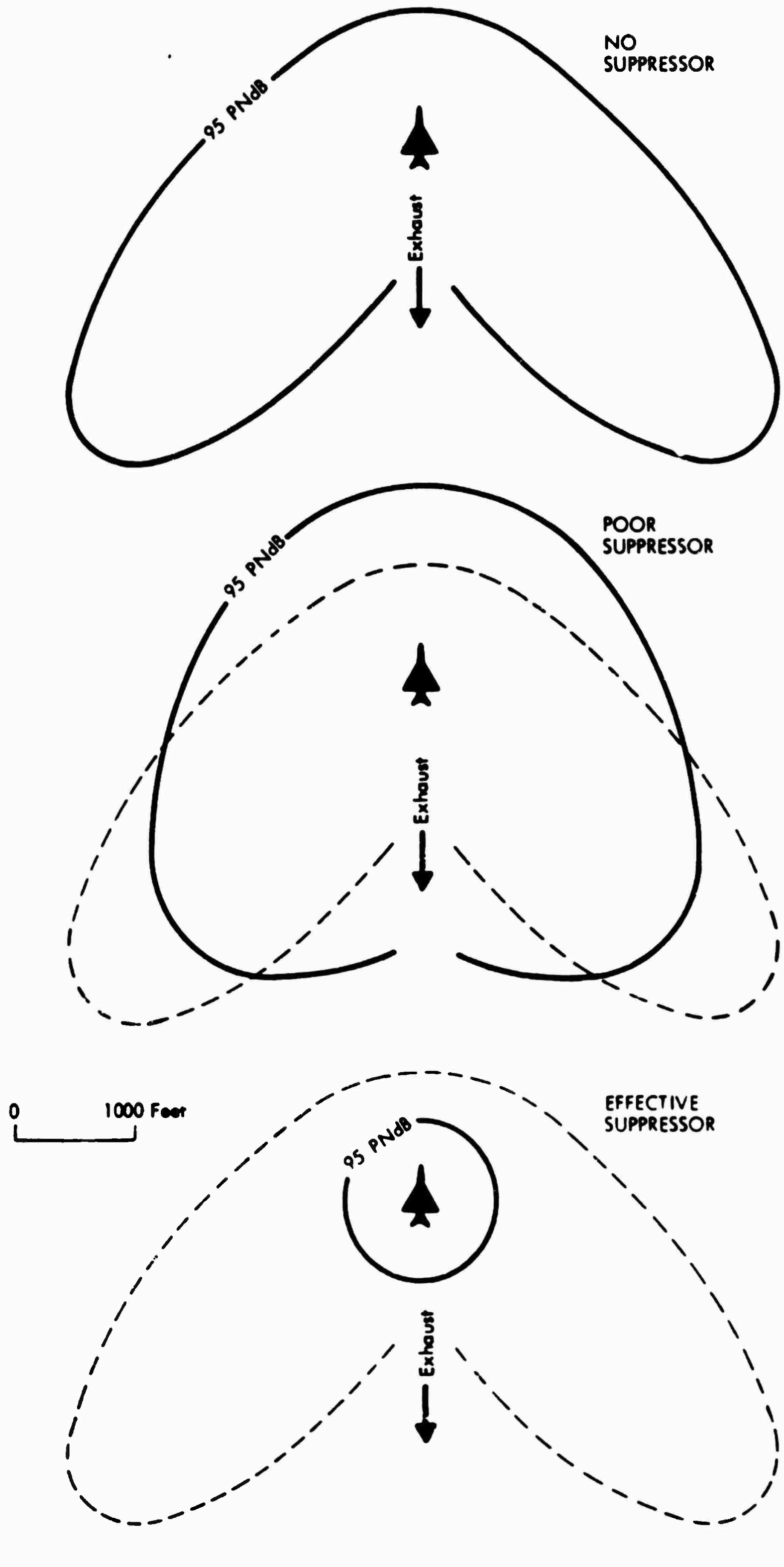
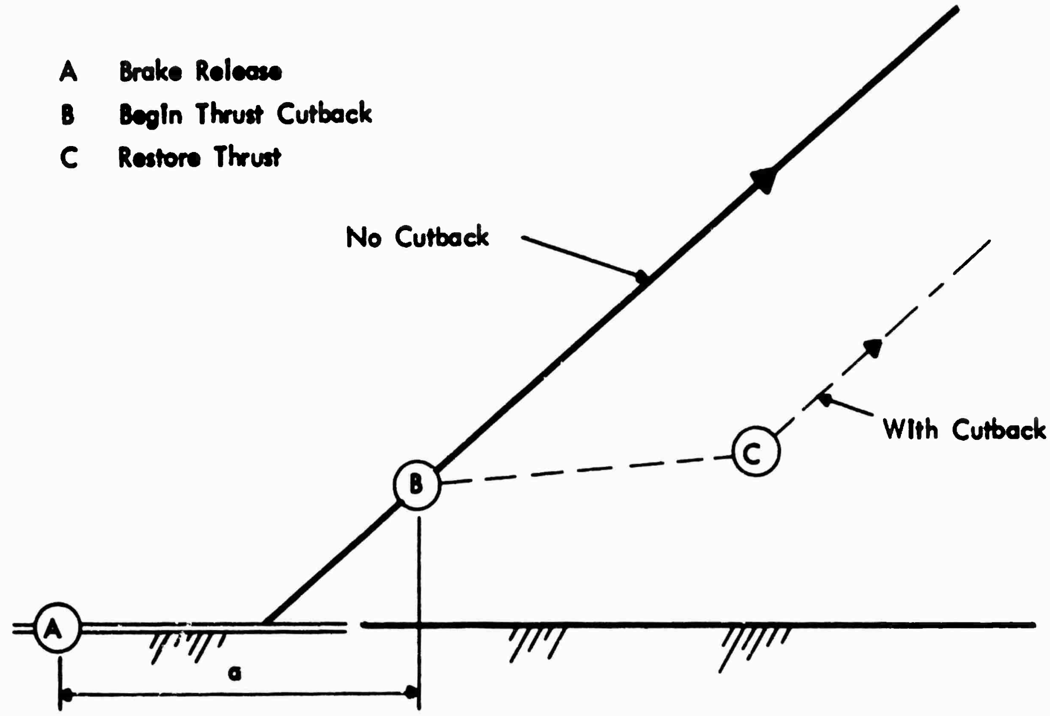


FIGURE 19. ENGINE RUNUP NOISE CONTOUR - WITH AND WITHOUT NOISE SUPPRESSOR

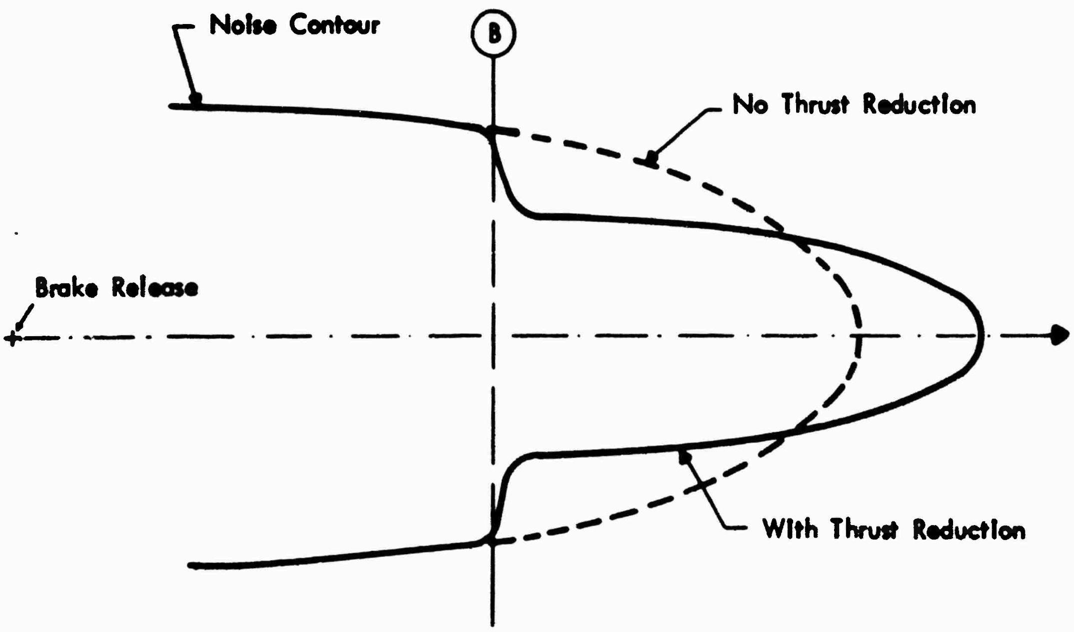
Noise abatement takeoffs, which typically imply a thrust reduction at some point along the takeoff path, may also be evaluated by the NEF procedures. Figure 20, shows in idealized form, a typical noise abatement takeoff. For some military aircraft the thrust cutback could be from afterburner to military or climb power at the edge of the airfield or before a sensitive community area.

As indicated by the PNL contour on the lower portion of the figure, at some point beyond the power cutback point, the benefits of a thrust reduction (as compared to the prior no-cutback procedure) may be offset by the lower altitude resulting from the power cutback position. The degree of noise benefits, as well as being tied initimately to the particular aircraft performance and noise characteristics, will also vary widely with ground location.

In an actual field situation, some aircraft will not be able to institute a power cutback, because of basic performance or mission constraints. Others may be able to cutback thrust in varying amounts. The NEF procedures allow these individual profile characteristics to be taken into account, and the resultant overall effect evaluated.



(a) TAKEOFF PROFILE



(b) NOISE CONTOUR COMPARISON

FIGURE 20. SIMPLIFIED NOISE ABATEMENT - TAKEOFF PROFILE AND NOISE CONTOUR

SECTION VII

AIRCRAFT DESIGN IMPLICATIONS

Aircraft noise has a number of implications on basic aircraft design and on military weapon system costs that have not been fully recognized.

The effects of aircraft noise on the aircraft itself, in terms of structural integrity and service life are well recognized and deservedly receive much attention during the aircraft design and testing stages. The needs for control of noise levels at crew positions and to consider the noise environment for maintenance personnel have also been recognized and are considered, in varying degrees, during the weapon system design. However, the influence of aircraft noise on communities and air bases has generally received little recognition in system design. This section seeks to point out some of the more direct implications of community noise and outline some of the technical evaluations that should be conducted.

In addition to any effect on the aircraft itself, an increase in aircraft noise, compared to the predecessor system, can lead to:

- lessened flexibility in stationing aircraft among air bases
- increased need for air base land acquisition
- needs for improved ground sound suppressor systems for handling ground maintenance operations
- degradation in air base/community relationships at individual air bases

Conversely, a quieter system will yield benefits in terms of increased flexibility in stationing aircraft and a reduction in need for attendant base expenditures to handle the aircraft system.

The impacts and costs can be quantified by comparing the noise characteristics of proposed systems with previous and existing weapons systems. In these comparisons, sets of NEF contours reflecting operations of projected and precedessor aircraft systems provide a basic planning tool. Such studies can be done for specific air bases, or for a generalized "model" air base.

It is important to identify, as early in the design stages as possible, any significant change in the noise characteristics of new aircraft. If major changes appear likely, design tradeoff studies should be undertaken. In some cases, potential weight or performance penalties for lower noise output engines, may be more than offset by the greater operating flexibility, reduced base operating costs, as well as possible benefits in the aircraft design and test programs.

In these early system design studies, noise comparisons of the type indicated in Figure 21 should be made.

1. The relative noise output should be compared, as shown in Figure 21 in terms of noise level versus distance characteristics.
2. Noise contours should be compared as shown in the lower portion of Figure 21. These contours reflect aircraft performance as well as noise output.

In the example shown, the increased noise output and better takeoff performance of system A is reflected in a broader but shorter noise "footprint."

Tradeoffs in operational procedures could be initially considered, even at an early stage in design. For example, could the aircraft takeoff on some training missions at partial afterburner, rather than full afterburner? Would the resulting reduction in engine noise output offset the decreased climb gradient?

Irrespective of the depth of design studies involving noise considerations, early definition of the far field noise characteristics of new weapon systems should be made, with noise information fed promptly to the air base planners, so that changes in noise exposure at individual air bases can be anticipated and integrated into the air base planning (see Section V).

Often, in the past, the noise information presented in "Environmental Statements" for new systems has been incomplete and vague. Although this lack of information may be necessary in early design stages, the noise information should be updated periodically during the system development as more detailed and accurate noise and performance data is obtained.

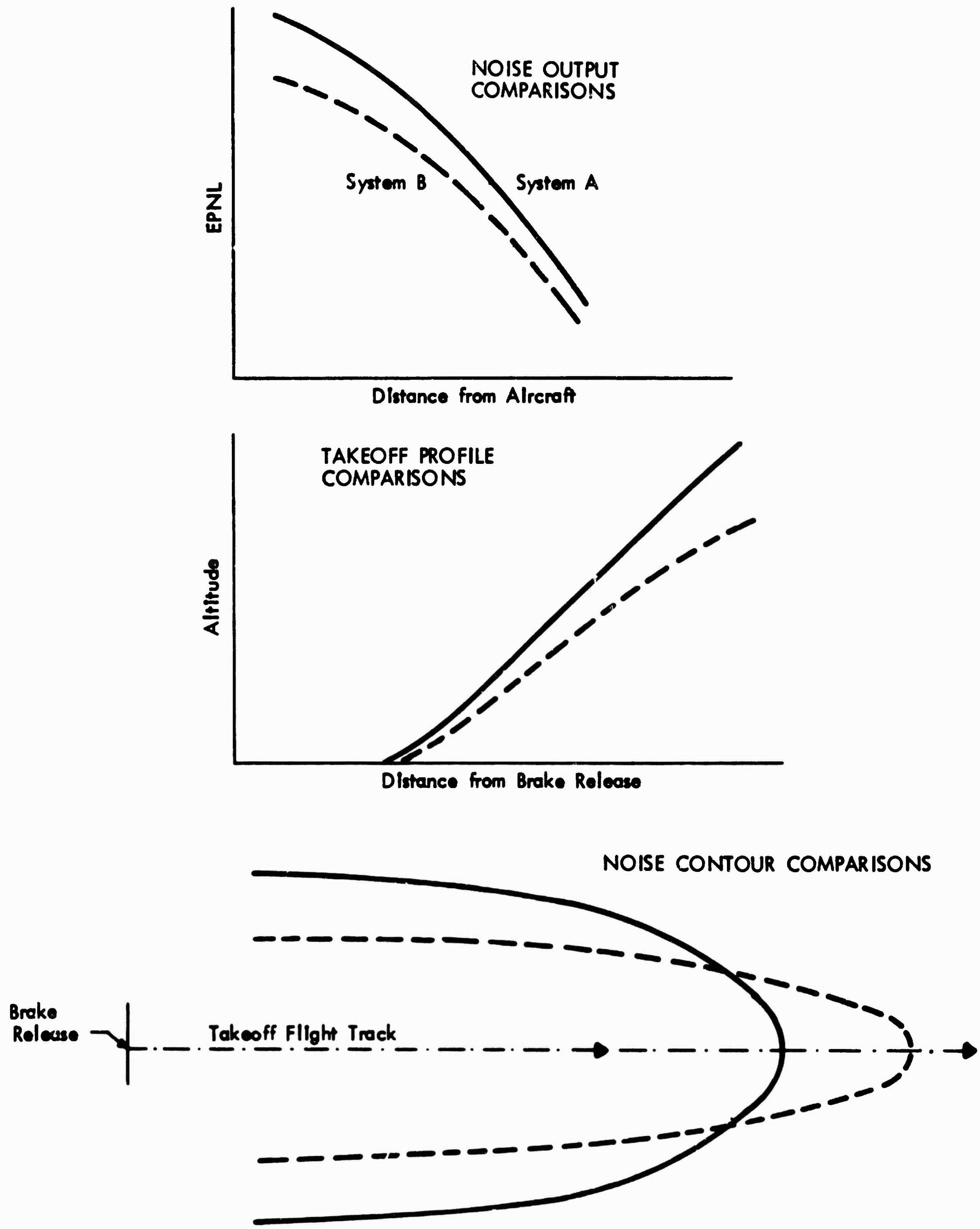


FIGURE 21. BASIC ELEMENTS IN AIRCRAFT NOISE COMPARISONS

BIBLIOGRAPHY

The Air Force community noise exposure procedures are documented in a series of technical reports, as follows:

- Air Force Report AMRL-TR-73-106, "Community Noise Exposure Resulting from Aircraft Operations: Technical Review."
- Air Force Report AMRL-TR-73-107, "Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data."
- Air Force Report AMRL-TR-73-108, "Community Noise Exposure Resulting from Aircraft Operations: Computer Program Operator's Manual."
- Air Force Report AMRL-TR-73-109, "Community Noise Exposure Resulting from Aircraft Operations: Computer Program Description."
- Air Force Report AMRL-TR-73-110, "Community Noise Exposure Resulting from Aircraft Operations: Acoustic Data on Military Aircraft."

A number of recent reports present a wealth of information on community and transportation noise. Among the more useful documents and reports are:

- U.S. Department of Housing and Urban Development, "Noise Abatement and Control: Departmental Policy, Implementation Responsibilities, and Standards." HUD Circular 1390.2. Establishes noise standards and implementation procedures in HUD programs.
- T. J. Schultz and N. M. McMahon, "Noise Assessment Guidelines." Washington, U.S. Department of Housing and Urban Development, 1971. 30 p. (USGPO $0.70) (PB 210 590). Implementation guidelines for HUD circular 1390.2. Guides to defining site exposure to noise from a variety of noise sources.
- T. J. Schultz, "Technical Background for Noise Abatement in HUD's Operating Programs," BBN Report 2005R, prepared for HUD. November 1971. (PB 210 591) (USGPO $2.00). Reviews means for describing and measuring community noise and for relating noise to human reactions. The report compares different community noise measures and results from laboratory and social surveys, and provides a comprehensive background for understanding HUD's new abatement policy. The report also provides extensive references to the technical literature.

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- U.S. Environmental Protection Agency, "Report to the President and Congress on Noise." December 1971. (PB 206 716). A comprehensive overview of effects of noise and their relative environmental impact, and outlines means and potential for controlling noise in the future. Existing legislation and regulation of noise in this country and abroad are summarized. The referenced Technical Information Documents used as a basis for preparing the report provide extensive information and references in particular study areas.
- H. E. Von Gierke, Chairman, "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure," EPA Aircraft/Airport Noise Study Report, July 1973 (NTID 73.4). Reviews methods of characterizing noise exposure around airports, reviews speech communication and annoyance effects of noise, and establishes the basis for the day/night average level as a recommended measure of noise exposure.
- U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," March 1974 (550/9-74-004). Identifies levels of noise exposure, in terms of the equivalent A-level over appropriate daily time periods, to protect against activity interference and hearing loss.

Noise considerations for community planning in the vicinity of airports is discussed in the following:

- R. D. Beland, et al, "Aircraft Noise Impact -- Planning Guidelines for Local Agencies," prepared for HUD, November 1972 (USGPO 2300-00214, $3.85).

Examples of the applications of NEF procedures to airport tradeoff studies are contained in the following:

- D. E. Bishop, R. D. Horonjeff, "Noise Exposure Forecast Contours for Airport Noise Tradeoff Studies at Three Major Airports," FAA Report FAA-NO-70-7, July 1970. Describes changes in NEF contours for various assumptions about noise abatement takeoffs and retrofit of civil aircraft as applied to operations at O'Hare International Airport, Chicago; John F. Kennedy Airport, New York; and Los Angeles International Airport, California.
- W. J. Galloway, et al, "Aircraft Noise Analyses for the Existing Air Carrier System," prepared for the Aviation Advisory Commission, September 1972 (NTIS). Evaluates courses of action and costs to alleviate noise exposure in the vicinity of airports, taking into consideration reduction of aircraft noise at the source, use of various aircraft operational procedures, and various means of achieving noise compatible land use. NEF contours are used to describe noise exposure.

REFERENCES

1. BBN Technical Report, "Land Use Planning Relating to Aircraft Noise," FAA, October 1964, including Appendix A, May 1965. Also published by the Department of Defense as AFM 86-5, TM 5-365, NAVDOCKS P098, "Land Use Planning with Respect to Aircraft Noise."

2. H. E. Von Gierke, Chairman, "Draft Report on Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure", Task Group 3, Environmental Protection Agency Aircraft/Airport Noise Report Study, June 1973.

3. T. J. Schultz, N. M. McMahon, Noise Assessment Guidelines, U.S. Department of Housing and Urban Development, 1971 (PB 210 590), USGPO, $0.70.

4. Standard Land Use Coding Manual, Urban Renewal Administration, Housing and Home Finance Agency and Bureau of Public Roads. Department of Commerce, 1st edition, January 1965, USGPO, $0.50.

5. G. D. Vest, "Protecting Airports and Their Neighbors Through the Environmental Land Use Planning Process," Hdqtrs, Air Training Command, Randolph Field, Texas, March 1973. Later incorporated as part of EPA Aircraft/Airport Noise Study Report, Task Group 6, "Military Aircraft and Airport Noise and Opportunities for Reduction Without Inhibition of Military Missions," NTID 73.7, July 1973.

6. D. E. Bishop, J. E. Randorff, "New Approaches in Developing Regulations for Land Development Near a Major Airport," 86th Meeting of the Acoustical Society of America, November 1973.

7. Air Force Report AMRL TR-73-106, "Community Noise Exposure Resulting from Aircraft Operations: Technical Review."

8. Air Force Report AMRL TR-73-107, "Community Noise Exposure Resulting from Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data."

9. Air Force Report AMRL TR-73-108, "Community Noise Exposure Resulting from Aircraft Operations: Computer Program Operator's Manual."

10. Air Force Report AMRL TR-73-109, "Community Noise Exposure Resulting from Aircraft Operations: Computer Program Description."

11. Air Force Report AMRL TR-73-110, "Community Noise Exposure Resulting from Aircraft Operations: Acoustic Data on Military Aircraft."

APPENDIX A

INFORMATION REQUIREMENTS FOR AIR BASE NOISE ANALYSES

INTRODUCTION

The USAF, as part of its continuing monitoring of the environmental effects of its operations, has developed an improved methodology for assessing the noise produced on the ground from aircraft flight and ground operations. To use these techniques, accurate information concerning the operations at each air base is needed. This document describes the specific information required and the standard forms to be used for reporting the information.

REPORTING REQUIREMENTS

The information required consists of air base layout descriptions, operational procedures, flight data, and ground runup information. Forms are supplied to report the necessary data in a standard format as follows:

1. Schedule of Restrictions and Limitations
2. Runway Utilization Schedule
3. Takeoff Schedule
4. Departure Procedure
5. Special Mission Description
6. Landing Schedule
7. T&G/FMLP Worksheet*
8. Runup Pad Utilization
9. Aircraft/Engine Test Schedule

In addition to these forms, an accurate map of the area around the air base must be supplied. This map should be approximately centered around the base and cover the area within an eight mile radius from the base. Experience has shown that Coast and Geodetic Survey (G&GS) topographical maps at a scale of 1 : 24,000 (1" = 2000') are ideally suited for this purpose.** To obtain coverage of a sufficiently large

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* Worksheet for touch-and-go (T&G) operations and, for Navy or Marine aircraft, field mirror landing practice (FMLP) operations.

**See section on U.S. Geological Survey maps, page A-10.

area it is usually necessary to splice a number of contiguous quadrangle sheets together with transparent tape. If C&GS maps are not available, other equivalent maps may be used. The map scale of such maps should be clearly marked on the map.

FLIGHT OPERATIONS

Calculating Volume of Operations Data

Flight operations are considered to take place during either the day (0701-2200 hours) or the night (2201-0700 hours). The number of daytime and the number of nighttime operations must be determined for each aircraft type. This number must be further broken down by flight path.

The flight path is the trajectory of an aircraft in space. The projection on the ground of the flight path is called the ground track. Many aircraft may follow the same ground track, but climb at different rates, therefore, it is meaningful to describe the operations in terms of a ground track and a set of aircraft/mission codes. For use in this context a mission constitutes a given set of operational parameters for an aircraft.

A list of the typical missions for the common aircraft in the USAF fleet is supplied to assist you in relating base operations to the standard missions. The numbers of aircraft of a given type flying closest to the missions provided should be calculated. If an aircraft is not listed or if none of the listed missions adequately describes the missions actually flown from the base, such missions should be described on the Special Mission Description form. Minor differences in power management or gross weight can be ignored when assigning mission numbers to aircraft types.

The list of aircraft/mission combinations will, in general, only list one entry for the aircraft type (e.g., F-4). In filling out the forms for a base the actual version of the aircraft should, however, be included so that when F-4D and F-4E aircraft both operate from the base they should be listed separately.

First one must determine the average number of total operations, by aircraft type, during the day and night periods. This information is generally available from operational records. In defining the "average" day, the base operations should be examined for at least one month to evaluate weekday versus weekend flying activity. If weekday activity totals more than twice the weekend activity, the average should be taken over week days only.

Monthly total operations should be examined over a yearly period to determine if there are significant fluctuations from month to month. The operations during the three month period containing the highest activity of the year should be averaged to determine the "average month" for noise computations unless it is clearly evident that separate noise exposure computations are desirable for active and inactive periods. If the most active month has less than twice the operations of the least active month, then separate noise computations are not warranted.

Having obtained the volume of operations on the typically busy day, one must now determine the number of operations on each runway. For each runway one must know the percentage utilization. This information may be available from operational data or may be estimated from climatological data on wind speed and direction. When the utilization percentages of the runways are multiplied by the number of aircraft of each type operating on the typically busy day, one arrives at the average number of aircraft which operate on a given runway.

The next step is to determine the number of aircraft of each type which follow a given ground track. Occasionally actual counts are available, but in any event operations personnel can supply an estimate of the relative utilization of the different flight tracks. The relative utilization of a given flight track for a given aircraft multiplied by the average number of aircraft of that type using that runway gives the actual number of operations over the given ground track. These numbers, by aircraft type, and by period of day are required on the standard forms supplied.

At many installations there are flight restrictions in effect. These would include, but are not limited to, altitude restrictions, noise abatement procedures, etc. If any restrictions are applicable, they should be listed on the Schedule of Restrictions and Limitations. One should also include the power management consequences of the restrictions, such as whether aircraft maintain speed and cutback power, or maintain power and accelerate, etc.

At some installations intersection takeoffs are made by certain types of aircraft. These operations should be included in the utilization percentages for the applicable runways. Touch-and-go and FMLP flights should not be included in the utilization percentages, since those are analyzed separately, and have their own special forms.

Reporting Air Base Layout

In addition to an accurate map of the area within an eight mile radius from the base (C&GS), it is advisable to have a copy of the base master plan available for reference. If possible, a copy should be submitted with the other materials.

The location and length of all active runways should be carefully compared to the base master plan to insure an accurate and current representation. This is necessary since in many instances the C&GS maps are not current enough to show the correct runway configuration. For each runway indicate the <u>usable takeoff length</u> by a solid line directly on the map. Do <u>NOT</u> include blast pads, overrun areas, etc.

For each active runway complete a Runway Utilization Schedule. Write in the spaces provided above and below the illustration the number of the runway, and complete the sentences with the percentage utilization obtained as discussed above. Exclude T&G and FMLP operations to arrive at the percentages. If the percentages vary with different type of aircraft, then the expanded schedule on the lower half of the page should be used to record the percentages, leaving the last two columns blank.

In either event the available runway landing length (from master plan or approach plates) for each side of the runway should be provided as well as the total length (corresponding to the solid line on the C&GS map).

Intersection takeoffs should be included in the percentages. In addition, one should state the number of takeoffs for a given aircraft that are intersection takeoffs. If, for example, all T-28 aircraft use an intersection takeoff from taxiway "F" then the percentage to be indicated in the percentage column of the expanded schedule is 100; if two-thirds of the takeoffs of T-28 aircraft on a given runway follow an intersection takeoff, the percentage listed in the expanded schedule should be 67, etc.

Flight Paths

Each takeoff procedure and each landing procedure that is in use at the base must be reported. The landing operations are reported on the "Landing Schedule" form, but takeoff operations may be reported on either the "Takeoff Schedule" or "Departure Procedure" form, depending on which is the most appropriate. Touch-and-go and Mirror Landing Practice operations are reported on a special FMLP/T&G worksheet. Each of these forms reports one and only one ground track, although there is no limit to how many different aircraft/mission combinations follow this ground track.

Each of the ground tracks should be indicated on the C&GS map. <u>Draw the tracks on an overlay rather than on the map itself</u>. If the flight paths form a complex pattern on the ground, make separate overlays, each one corresponding to one type of operation. In any event the FMLP/T&G operations should be drawn on a different overlay from the other operations.

It is necessary to identify each ground track by a unique code to establish a cross reference between each ground track and the filled out forms. The ground tracks emanating from a runway are labeled by a letter starting with "a." Since this does not make the ground track label unique it is preceded by the runway number and a slash. To distinguish landings from takeoffs the letter "L" or "T" is used after the slash. A takeoff from runway 35 would then be coded, for example, 35/Ta, while a landing might be 35/La.

Takeoff Schedule

The Takeoff Schedule is used to list a given ground track directly in terms of line segments and circle arcs. This description should be listed on the Takeoff Schedule form, and the corresponding track drawn on the overlay. The first entry should be a straight section and should start from the point of brake release. Describe the rest of the track in terms of turns of fixed radius and straight line sections. If the turn flown by the aircraft is not a constant radius, one may approximate such a turn by two or three constant radius sections each with a different radius. The straight line section ("Proceed ___ ft") between two such curved segments must then be set equal to zero. Do not leave the entry blank! Draw the corresponding track on the C&GS map overlay and identify it with the same code as used on the Takeoff schedule for this ground track.

Write the number of operations in the boxes provided. Include the number of operations for each aircraft type on each mission which follow this ground track. These are the numbers obtained as explained above from volume of operations and utilization data. Complete last column only for those aircraft making intersection takeoffs.

Departure Procedures

Often, takeoff ground tracks may vary with the performance of the different types of aircraft. An example would be "climb to 4000 feet then proceed direct to XYZ VOR." In these cases it is simpler to use the Departure Procedure instead of the Takeoff Schedule, since a separate ground track would result from each type of aircraft, and therefore also a separate Takeoff Schedule. When departure procedures are defined in terms of an IFR clearance, these may be used directly. Such clearances can be listed on the "Departure Procedure" form. An acceptable definition, for example, is: "Depart on runway heading until reaching 4000 feet, then turn to heading 186 to intercept the 120 radial of TAC-42."

When such instructions are given indicate the location of the navaids used directly on the C&GS map, using standard symbols to identify the location and indicate the code (e.g., TAC-42) next to it. If the navaid is located off the map, the latitude and longitude coordinates of the navaid must be provided with a precision of at least 0.1 minutes of arc.

Obviously where SIDs are flown they can be listed directly. It must be pointed out, however, that SIDs are generally "lost communications" procesures, and that in normal day-to-day operations aircraft may well follow a different procedure. One must, therefore, critically analyze the SID and only use it if it is really followed exactly. Otherwise, one should list the procedure actually flown, rather than the published SID.

On the Departure Procedure overlay, indicate the range of ground tracks which one would reasonably expect to result from each procedure.

Landings

On the landing overlay, draw the ground tracks appropriate for landings and label them with the code used on the Landing Schedule. The description on the schedule starts from the initial approach fix or some similar suitable point, and stops at touchdown. For all approaches which use a constant rate of descent a nominal glide slope may be defined. If this is given on the schedule it will be used and no altitude information needs to be specified. If the rate of descent is not constant, altitude information must be supplied. Although an altitude space is provided for every line it is only necessary to give the altitudes at those points where the rate of descent changes.

For those aircraft that use an overhead approach, specify the altitude five miles from runway threshold, the break altitude, and the pattern altitude. Provide a sketch of the flight track on the ground for the complete approach pattern in the form of an overlay to the C&GS map.

For landings that use the VFR traffic pattern follow the same procedure and indicate how and where the entry into the pattern is made.

Touch-and-go and FMLP Operations

Special attention should be given to all training flight paths, such as touch-and-go or mirror landing practice patterns. Again it is necessary to specify the number of operations during the day and nighttime periods (0701-2200 and 2201-0700). The extent of the pattern for one aircraft in the pattern, for the average number in the pattern, and for the maximum in the pattern should be indicated on an overlay. It is necessary that this overlay be separate from those for other operations.

The description of the operational parameters is entered on the T&G/FMLP worksheet. Use a separate sheet for each aircraft type in each pattern.

STATIC ENGINE RUNUPS

Static engine runups, whether for maintenance or preflight checkout, can produce significant noise intrusions in nearby communities. To assess the impact of ground runup noise, the following types of information are required.

1. Location of all runup pads.
2. Direction of engine exhaust at each pad.

3. Noise suppression devices available.

4. Type aircraft or engine using each pad.

5. Engine power settings and length of test.

6. Time of day the runups are performed.

The following three steps outline the process for specifying the required information:

1. Identify all runup areas.

2. Describe all runup test procedures.

3. Determine average daily utilization of each runup area for each test procedure.

Step 1. Location and Orientation of Runup Pads

A "runup pad" is to be considered as any location where a stationary aircraft or bare engine is operated on a regular basis <u>in excess of idle power</u>. Typically these areas include:

1. Bare engine test stands.

2. Flightline parking stalls.

3. Maintenance runup cells.

4. Preflight runup area (prior to takeoff).

The first step is to identify the location of all runup pads. In most cases, a map of the airbase will cover all of the locations mentioned above. On this map the following should be clearly indicated:

1. Mark with a large dot the location of every runup pad (do not show pads where engine power never exceeds idle).

2. For each dot placed on the map attach an arrow indicating the <u>direction of the engine exhaust</u>. An example is shown in Figure 1. The direction of the arrow is important, thus care should be taken in accurately showing the correct aircraft orientation.

3. Label each dot so that it can later be referred to by a name or number. The label may be any combination of letters, numbers, or punctuation marks, but must be restricted to eight characters or less (including any punctuation characters). An example is shown in Figure 1.

4. Be certain a north arrow appears on the map.

Step 2. Define Runup Tests

In almost all cases an aircraft and/or engine is brought to the runup area, one or more tests are performed, and the runup area is cleared. These tests may be leak tests, trim tests, or any one of a number of basic procedures followed by flight and maintenance personnel during engine servicing and checkout. Typically, a test involves running one or more engines at various power settings for some nominal period of time. The specific information required for each test is:

1. Type of aircraft and/or engine.
2. Type of noise suppressor used (if any).
3. Number of engines operating.
4. Engine power setting.
5. Total length of time engine is operating at each power setting.

A partially completed form is shown in Figure 2. Note that each test is numbered and the details of each power setting are tabulated in the appropriate columns.

The most difficult task in completing this form is determining the total length of time the engine is operating at the various power settings. It is acknowledged that there is rarely a defined time schedule for these tests, and the total time the engine is operated at any given power setting can easily vary by a factor of two or more from one test to the next. There are essentially two methods for determining these times. In order of preference, they are:

1. Provide on-site personnel to measure times for 10 to 20 tests, and determine average values.
2. Obtain best estimates from knowledgeable personnel.

The means by which this timing data was obtained should be noted in the appropriate column of the form.

Step 3. Runup Pad Utilization

Each runup pad identified on the base map in Step 1 will be used for one or more of the tests described under Step 2. At this point, the average number of times per day that each test is undertaken at the various pads must be determined. A sample form is shown in Figure 3. Every pad identified in Step 1 should appear on this form. The frequency of the various tests will, of course, vary from pad to pad. Frequently, a single aircraft may be on a pad for several days with long shutdown periods before the test is completed. This is still to be counted as one test. Runup areas frequently have average utilizations of less than one test per day. In other cases a test may start during the day and extend into the night, or vice versa. For reporting purposes, use the starting time of the test to establish whether the test was performed during daytime or nighttime.

EXAMPLE OF FLIGHT OPERATIONS

To illustrate the method described in the 'Flight Operations' section of this appendix, we will go through the steps necessary to fill out the forms for flight operations at a base. The ground runup operations were already shown in the 'Static Engine Runups' section.

Assume an airbase with two intersecting runways 01-19 and 06-24. (We will only look at runway 06 to keep the number of forms to a minimum.) The base operations per year are as follows:

F-4D	15000
F-4E	5000
F-8	16000

There are no F-4 operations on weekends, but 10% of the F-8 operations do take place over the weekend. Twenty percent of all operations take place during the night.

To find the daily averages required, we calculate as follows. F-4 operations take place only during weekdays (260 per year). Therefore divide the total number of operations by 520, since total operations is landings plus takeoffs. This gives us for average takeoffs or landings 28.846 F-4D and 9.615 F-4E. The F-8 operations also take place over the weekend, but since the week end comprises 2/7 = 28.6% of the total time but accounts for 10% of operations the weekend contribution is not considered. Therefore, the number of operations to be considered is 16000 - 1600 = 14400. This becomes 27.692 per day. Therefore, we have

TOTAL DAILY OPERATIONS ON BASE

Takeoffs	Total	Day	Night
F-4D	28.846	23.077	5.769
F-4E	9.615	7.692	1.923
F-8	27.692	22.154	5.538

Next the following runway percentages are determined.

R/W	Day	Night
01	5%	0%
06	60%	80%
19	10%	0%
24	25%	20%

These percentages are for takeoffs as well as landings. During the day both runways are in use, but at night 01-19 is closed. Note that the percentages add to 100% for each of the periods: The runway is 10000 feet long and runway 24 has a 1300 feet displaced threshold. The percentages are shown in Figure 4. If we look at runway 06 we find that it is used as follows.

Runway 06 Takeoffs or Landings	Day	Night
F-4D	13.846	4.615
F-4E	4.615	1.538
F-8	13.292	4.430

These numbers are obtained by multiplying the number of daily operations by the runway percentages (e.g., 23.077 x 60% = 13.846 and 5.769 x 80% = 4.615).

There are three takeoff procedures and one landing procedure for R/W 06.

1. Takeoff straight out. This is done by 30% of F-4 and 60% of F-8 aircraft taking off from 06.
2. Takeoff and turn 60° right three miles past the runway and proceed straight out. All aircraft will turn with a 13,000 feet turn radius. This procedure is followed by 30% of F-4 and 5% of F-8 taking off from 06. (Note that three miles = 18000 feet plus 10000 feet because we start from brake release!)
3. Takeoff along runway heading to 4000 feet AGL, turn to heading 186 to intercept the 120 radial of TAC-42. This is used by 40% of F-4 and 35% of F-8.
4. ILS landing with 2.85° glide slope followed by all landings.

We will calculate the numbers of aircraft following each procedure. Since 80% of F-4 and 60% of F-8 operations on Runway 06 follow the first takeoff procedure we multiply the number of operations by the percentages. For example these are 13.846 x 30% = 4.154 F-4D aircraft per day which use this procedure and 4.615 x 30% = 1.385 per night, etc. These numbers have been multiplied out and entered on the appropriate figures, which are labeled Figures 5-8.

Similar calculations can be performed for each of the other runways following the same outline. It is best to calculate these numbers runway by runway and leave the standard forms in the order in which they were filled out, since this is the logical order for further processing at the computer center.

When all forms are filled out, including those for ground runup operations, they should be counted, page numbered, and listed on the transmittal letter. A partially filled out letter is shown in Figure 9.

U.S. GEOLOGICAL SURVEY MAPS

The United States Department of the Interior Geological Survey publishes the following information regarding their maps.

The Geological Survey is making a series of standard topographic maps to cover the United States, Puerto Rico, Guam, American Samoa, and the Virgin Islands. Under the plan adopted, the unit of survey is a quadrangle bounded by parallels of latitude and meridians of longitude. Quadrangles covering 7½ minutes of latitude and longitude are published at the scale of 1:24,000 (1 inch = 2,000 feet). Quadrangles covering 15 minutes of latitude and longitude are published at the scale of 1:62,500 (1 inch = approximately 1 mile). A few special maps are published at other scales.

Each quadrangle is designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining published quadrangle maps. The maps are printed in three colors. The cultural features, such as roads, railroads, cities, and towns, as well as the lettering, are in black; the water features are in blue; and the features of relief, such as hills, mountains, and valleys, are shown by brown contour lines.

The contour interval differs according to the scale of the map and the relief of the country. On maps that contain supplemental information additional colors are used, such as green for woodland areas and red for highway classification, urban areas, and United States land lines. A booklet describing topographic maps and symbols is available free upon request.

Further information concerning maps may be obtained from the Map Information Office, Geological Survey, Washington, D.C. 20242.

How to Order Maps

Map Selection: A map should be ordered by name, series, and State in which it is located. In many instances, an area is covered by two maps which carry the same name, but are published at different scales. Where this occurs, it is especially important that the map order include the series designation, such as 7½-minute, 15-minute, or 1:250,000.

Most topographic quadrangle maps are available with or without green woodland overprint. Maps showing woodland overprint will be supplied unless maps without the overprint are specified. The Geological Survey does not supply mounted maps and does not publish maps in county units.

An order form is included with each index, but maps may be ordered without a form. The name, address, and zip code of the purchaser should be typed or printed on all orders, and the maps desired should be listed alphabetically.

Map Prices and Shipment: Standard quadrangle maps published in the 7½ or 15-minute series are priced at 50 cents a copy. Prices of other maps listed in this index are indicated in the descriptive text. On an order amounting to $20 or more at the list price, 20% discount is allowed; on an order amounting to $100 or more at the list price, 40% discount is allowed.

Prepayment is required and must accompany each order. Payment may be made by money order or check payable to the Geological Survey, or cash (the exact amount) at sender's risk.

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Residents of Alaska may order Alaska maps or an index for Alaska from the *Distribution Section, U.S. Geological Survey, 310 First Avenue, Fairbanks, Alaska 99701.*

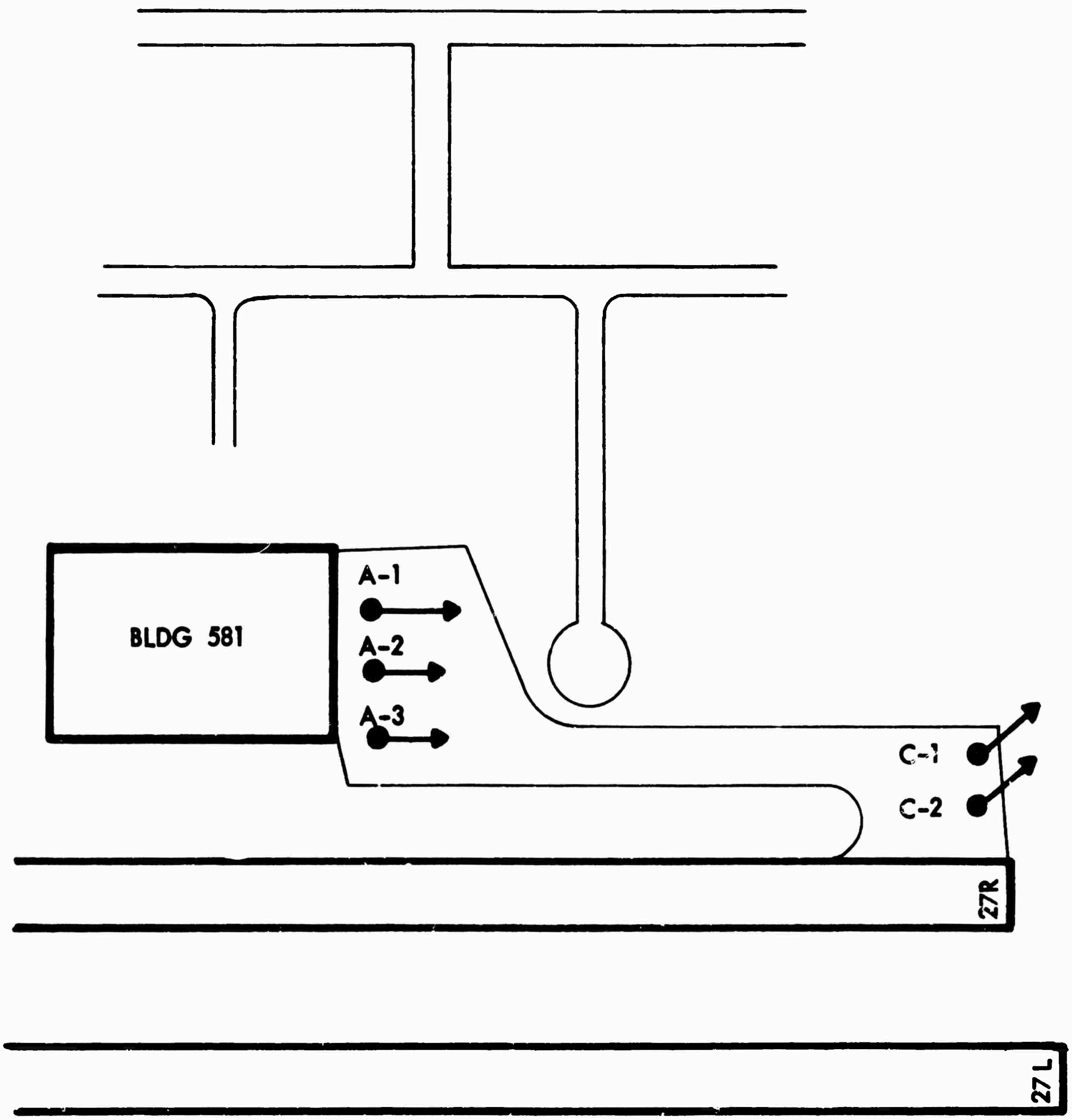


FIGURE 1. DETAIL OF AIR BASE MASTER PLAN WITH RUNUP PADS

Test	Aircraft and/or Engine	Type Suppressor (if any)	No. of Engines Operating	Engine Power*	Total Time (min)	Analysis
1	F-4D	NONE	1	100%	2	ESTIM.
		"	2	100%	5	"
		"	2	90%	15	"
		"	2	60%	120	"
2	F-4D	M560-43	1	A/B	1	ESTIM.
		M560-43	2	100%	2	"
		NONE	2	90%	5	"
3	F-8	NONE	1	A/B	1.7	MEAS.
		"	1	100%	2.5	"
		"	1	80%	60	ESTIM.
4	J-57	NONE	1	60%	120	ESTIM.

*Engine power is given in terms of (check one):

___ % RPM

___ % Thrust

___ Other

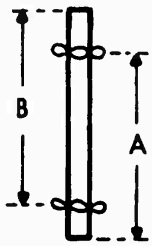
FIGURE 2.

Runup Pad	Test	Number of Runups 0701-2200	Number of Runups 2201-0700
A-1	2	0.5	0.1
	3	4.1	0.0
A-2	2	0.6	0.0
	5	0.1	2.2

FIGURE 3.

RUNWAY UTILIZATION SCHEDULE Page 17 of 46

Runway 06 is in use for takeoffs 60 % of the day, 80 % of the night, and



is in use for landings 60 % of the day, 80 % of the night.*

Runway length (A) available formlandings is 10,000 ft.

Runway 24 is in use for takeoffs 25 % of the day, 20 % of the night, and

is in use for landings 25 % of the day, 20 % of the night.

Runway length (B) available for landings is 8700 ft.

Total usable takeoff runway length is 10,000 ft.

Expanded Schedule: (List variable percentages and intersection takeoffs here)

Runway & Operation	%Day	%Night	Aircraft Type	Mission Number	From Inter section with	Remaining Runway Length
/						
/						
/						
/						
/						
/						
/						
/						
/						
/						
/						

FIGURE 4.

Ground Track Code 06/Ta

Takeoff from Runway

Proceed 150,000 ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Check here if continued overleaf ☐

This ground track is followed by these aircraft:

Aircraft Type	Mission* Number	Number of Takeoffs 0701-2200	2201-0700	(Start at intersection with:)
F-4D	1	4.154	1.385	
F-4E	1	1.385	0.461	
F-8	1	7.975	2.658	

*If no standard mission applies write SPECIAL in this column and complete a Special Mission Description form.

FIGURE 5.

TAKEOFF SCHEDULE

Ground Track Code 06/T6

Takeoff from Runway

Proceed 28,000 ft

Turn 60 ° to the RIGHT with radius 13,000 ft

Proceed 150,000 ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Turn ______ ° to the ______ with radius ______ ft

Proceed ______ ft

Check here if continued overleaf ☐

This ground track is followed by these aircraft:

Aircraft Type	Mission Number*	Number of Takeoffs 0701-2200	Number of Takeoffs 2201-0700	(Start at intersection with:)
F-4D	1	4.154	1.385	
F-4E	1	1.385	0.461	
F-8	1	0.665	0.222	

*If no standard mission applies write SPECIAL in this column and complete a Special Mission Description form.

FIGURE 6.

DEPARTURE PROCEDURE

For departures from Runway 06 the following clearance is given:

Climb to 4,000 FT.
Turn to heading 186 and intercept 120 radial of TAC-42

(If this procedure is a published SID, attach a copy and check here ☐)

The procedure applies to the following aircraft:

Aircraft Type	Mission Number	Number of Takeoffs 0701-2200	Number of Takeoffs 2201-0700	(Start at intersection with:)
F-4D	1	5.538	1.846	
F-4E	1	1.846	0.615	
F-8	1	4.652	1.551	

Navaids used in this procedure are located as follows:

Navaid Code	On Map?	Latitude	Longitude
TAC-42	YES		

FIGURE 7.

LANDING SCHEDULE

Page 21 of 46

Ground Track Code 06/LC

Landing into Runway 06

Glide Slope 2.85°

Proceed ______ ft from alt. __________ to alt. _________ ft AGL *

Turn _________ ° to the _______ with radius _______ ft to ___________ AGL

Proceed ______ ft to ________ AGL

Turn _________ ° to the _______ with radius _______ ft to ___________ AGL

Proceed ______ ft to ________ AGL

Turn _________ ° to the _______ with radius _______ ft to ___________ AGL

Proceed ______ ft to ________ AGL

Turn _________ ° to the _______ with radius _______ ft to ___________ AGL

Proceed ______ ft to ________ AGL

Check here if continued overleaf ☐

This ground track is followed by these aircraft:

Aircraft Type	Number of Landings	
	0701-2200	2201-0700
F-4D	13.846	4.615
F-4E	4.615	1.538
F-8	13.292	4.430

* If a nominal glide slope is used, altitudes need not be given. Only the altitudes at those points where the rate of descent changes need to be specified in other cases.

FIGURE 8.

TRANSMITTAL LETTER

To: ______________________ From: ______________________

______________________ ______________________

______________________ ______________________

Transmittal of operational data for: FALCON A.F.B

Standard Form Type	Quantity
Schedule of Restrictions and Limitations	0
Runway Utilization Schedule	2
Takeoff Schedule	12
Departure Procedure	7
Special Mission Description	1
Landing Schedule	7
FMLP / T&G Worksheet	
Runup Pad Utilization	5
Aircraft / Engine Test Schedule	8
Total Forms Enclosed	42

Item	✓	Check if item is enclosed, else indicate alternate mode of shipment
C & G S Map	✓	
Takeoff Overlay	✓	
Departure Overlay	✓	
Landing Overlay	✓	
Combined Overlay		
FMLP / T & G Overlay		
Base Master Plan Map	✓	

Data prepared by Approved by:

Signature ______________________ ______________________

Name ______________________ ______________________

Telephone ( ) ______ - ______ ______________________

FIGURE 9.

TRANSMITTAL LETTER

To: ______________________ From: ______________________

______________________ ______________________

______________________ ______________________

Transmittal of operational data for: ______________________

Standard Form Type	Quantity
Schedule of Restrictions and Limitations	
Runway Utilization Schedule	
Takeoff Schedule	
Departure Procedure	
Special Mission Description	
Landing Schedule	
FMLP / T&G Worksheet	
Runup Pad Utilization	
Aircraft / Engine Test Schedule	
Total Forms Enclosed	

Item	✓	Check if item is enclosed, else indicate alternate mode of shipment
C & G S Map		
Takeoff Overlay		
Departure Overlay		
Landing Overlay		
Combined Overlay		
FMLP / T & G Overlay		
Base Master Plan Map		

Data prepared by Approved by:

Signature ______________________ ______________________

Name ______________________ ______________________

Telephone ( ) ____-________ ______________________

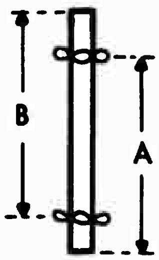
SCHEDULE OF RESTRICTIONS AND LIMITATIONS

Page______of______

List all restrictions and special procedures in effect at the base:

RUNWAY UTILIZATION SCHEDULE　　　　Page _____ of _____

Runway _______ is in use for takeoffs ___% of the day, ___% of the night, and



is in use for landings ___% of the day, ___% of the night.*

Runway length (A) available for landings is ________ ft.

Runway _______ is in use for takeoffs ___% of the day, ___% of the night, and

is in use for landings ___% of the day, ___% of the night.

Runway length (B) available for landings is ________ ft.

Total usable takeoff runway length is ___________ ft.

Expanded Schedule: (List variable percentages and intersection takeoffs here)

Runway & Operation	%Day	%Night	Aircraft Type	Mission Number	From Inter section with	Remaining Runway Length
/						
/						
/						
/						
/						
/						
/						
/						
/						
/						
/						

TAKEOFF SCHEDULE

Page _____ of _____

Ground Track Code ____/T____

Takeoff from Runway

Proceed _______ ft

Turn __________ ° to the _______ with radius __________ ft

Proceed _______ ft

Turn __________ ° to the _______ with radius __________ ft

Proceed _______ ft

Turn __________ ° to the _______ with radius __________ ft

Proceed _______ ft

Turn __________ ° to the _______ with radius __________ ft

Proceed _______ ft

Check here if continued overleaf ☐

This ground track is followed by these aircraft:

Aircraft Type	Mission Number*	Number of Takeoffs 0701-2200	Number of Takeoffs 2201-0700	(Start at intersection with:)

*If no standard mission applies write SPECIAL in this column and complete a Special Mission Description form.

DEPARTURE PROCEDURE

Page _____ of _____

For departures from Runway_____ the following clearance is given:

(If this procedure is a published SID, attach a copy and check here[ ])

The procedure applies to the following aircraft:

Aircraft Type	Mission Number	Number of Takeoffs 0701-2200	Number of Takeoffs 2201-0700	(Start at intersection with:)

Navaids used in this procedure are located as follows:

Navaid Code	On Map?	Latitude	Longitude

SPECIAL MISSION DESCRIPTION

Page______ of______

To record a non-standard mission it is necessary to give the power settings, the aircraft speed, and either the altitude or the rate of climb as a function of distance from brake release.

Aircraft Type ______ Engine Type ______ Gross Weight ______

Distance from Brake release	0						
Altitude	0						
Rate of Climb							
Power Setting							
Aircraft Speed	0						
Comments	Br. Rel.	Liftoff					

This special mission is applicable to flights over ground track ______

Further Comments:

LANDING SCHEDULE

Page ______ of ________

Ground Track Code ____/L____

Landing into Runway __________ Glide Slope _______°

Proceed _______ ft from alt. ___________ to alt. __________ ft AGL *

Turn __________° to the _______ with radius _______ ft to ____________ AGL

Proceed _______ ft to ________ AGL

Turn __________° to the _______ with radius _______ ft to ____________ AGL

Proceed _______ ft to ________ AGL

Turn __________° to the _______ with radius _______ ft to ____________ AGL

Proceed _______ ft to ________ AGL

Turn __________° to the _______ with radius _______ ft to ____________ AGL

Proceed _______ ft to ________ AGL

Check here if continued overleaf ☐

This ground track is followed by these aircraft:

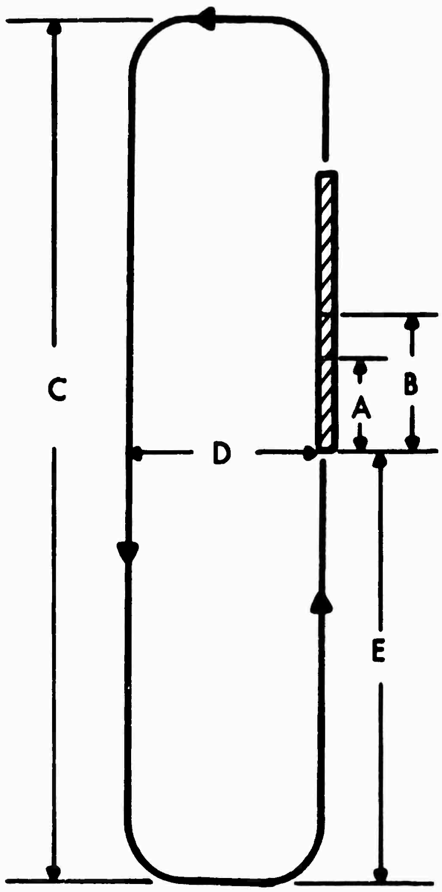
Aircraft Type	Number of Landings	
	0701-2200	2201-0700

* If a nominal glide slope is used, altitudes need not be given. Only the altitudes at those points where the rate of descent changes need to be specified in other cases.

T&G / FMLP WORKSHEET

Page ______ of ______

(LEFT-HANDED PATTERN)



Aircraft Type ____________________

Average Number T&G (0701-2200) ________

(2201-0700) ________

PATTERN DESCRIPTION:

I. Climb:

Engine Power ____________________

Distance (A) to Touchdown ________ ft

Distance (B) to Liftoff ________ ft

II. Level Flight:

Engine Power ____________________

Length (C) of Pattern ________ ft

Pattern Altitude (AGL) ________ ft

Aircraft Speed ____________ kts

III. Descent:

Engine Power ____________________

Width (D) of Pattern ________ ft

Length (E) of Final ________ ft

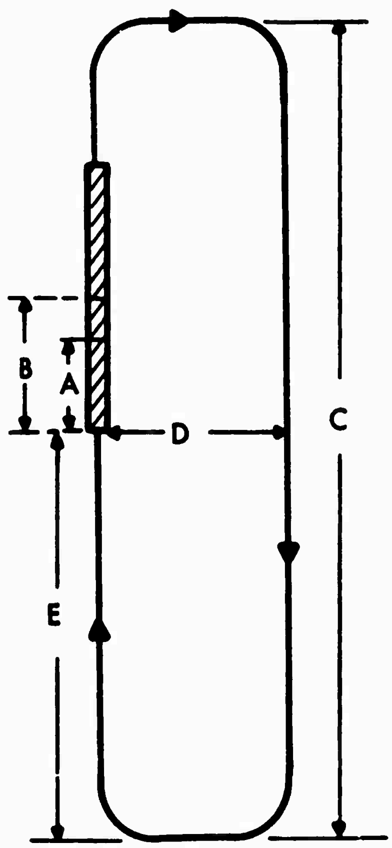
Nominal Glide Slope ________ deg.

This worksheet describes the operations on runway ____________

T&G / FMLP WORKSHEET

Page ______ of ______

(RIGHT-HANDED PATTERN)



Aircraft Type ______________________

Average Number T&G (0701-2200) ________

(2201-0700) ________

PATTERN DESCRIPTION:

I. Climb:

Engine Power ______________________

Distance (A) to Touchdown ________ ft

Distance (B) to Liftoff ________ ft

II. Level Flight:

Engine Power ______________________

Length (C) of Pattern ________ ft

Pattern Altitude (AGL) ________ ft

Aircraft Speed ________ kts

III. Descent:

Engine Power ______________________

Width (D) of Pattern ________ ft

Length (E) of Final ________ ft

Nominal Glide Slope ________ deg.

This worksheet describes the operations on runway

RUNUP PAD UTILIZATION

Page______ of_______

Runup Pad	Test	Number of Runups	
		0701-2200	2201-0700

AIRCRAFT / ENGINE TEST SCHEDULE

Page _____ of _______

Test	Aircraft and/or Engine	Type Suppressor (if any)	No. of Engines Operating	Engine Power*	Total Time (min)	Analysis

*Engine power is given in terms of (check one):

___ % RPM

___ % Thrust

___ Other

APPENDIX B

NOISE MONITORING CONSIDERATIONS

Questions occasionally arise as to the desirability of making field noise measurements to confirm or validate predicted noise exposure or noise level contours. Of course the crucial test of contour validity is field verification by measurement. However, field measurements of sufficient reliability to check prediction may be difficult, time consuming and costly.

A major reason for high costs of satisfactory field noise measurements is the fact that repeat measurements of noise events will rarely yield the same exact number -- there may well be considerable variability in the measurements. Major sources of such variability are discussed in Section III. Variability may be observed when measuring noise levels produced by similar operations, aircraft takeoffs for example. Variability will extend to measurements of the noise exposure over 24-hour periods, from day to day at a given position near an air station.

Because of this variability, it is necessary to take repeat measurements to be able to demonstrate a certain confidence in the end results. The greater the variability, the more measurements that are needed to establish a noise level to a given level of confidence, as judged by accepted statistical methods.

Typically, noise monitoring for purposes of validating noise levels or noise exposure would be undertaken for one or both of the following reasons:

1. There are uncertainties in the basic assumptions with regard to aircraft flight path, aircraft flight profiles or noise data. For example, due to diversities in training missions at a base, one suspects considerable variability in aircraft takeoff profiles and tracks, leading to questions as to how well computed noise values compare with field measured data. Another example arises with ground runup operations where noise level projections at large distances may be questioned, particularly when there are large variations in weather or irregular terrain between the aircraft and the position of interest.

2. There is a need to determine the noise exposure to close tolerances. Such conditions often arise where noise criteria have been set up for land zoning and/ or for land development. For example, HUD noise

policy guidelines make eligibility for Federal funding for residential development dependent upon the NEF value on the site.

Because of the decibel scales used in noise measures, the translations of tolerances in NEF values into changes in contour locations on the ground can easily result in requests for very small tolerances in noise measurement which are either impractical or extremely costly. For example, the following table shows the approximate distances involved on the ground for a change of 2 dB:

Propagation Distance, ft.	Contour Changes, ft.
1,000	120
2,000	250
5,000	600
10,000	1,200

Until recently, it has generally been necessary to put a man in the field, equipped with a sound level meter, or more complex sound recording equipment, to make aircraft noise measurements. Noise levels would be observed directly on the sound level meter, or the noise signal would be recorded on tape for later laboratory analysis. This can be an expensive procedure, particularly when large numbers of measurements are required. Recently, portable field instrumentation has been developed that can collect noise data, unattended, over periods of one or two days or more without servicing.* Such equipment markedly reduces the cost and increases the ease of making field measurements over extended time periods. The availability of such equipment will undoubtedly increase the amount of field monitoring that will be done in the future.

The number and extent of field measurements will be largely dependent upon the degree of accuracy needed in the measurements and the expected variability in noise levels. Figure B-1 provides a guide for estimating the number of measurements needed to establish a ninety percent confidence interval in the mean value. To use this chart one must estimate the expected variability in terms of the expected sample standard deviation. From observed measurements near airports, standard deviations can range from less than 2 dB to over 7 dB. To insure a ninety percent confidence level in the average value being within ± 2 dB of the true value, one can see from Figure B-1 that five measurements are needed for the sample if the standard deviation is 2 dB. When the standard deviation is seven, some 35 measurements would be needed to establish the average to the degree of confidence.

*In addition, some civil airports have installed permanent monitoring stations which permit continued monitoring of noise at a number of positions around the airport.

One must distinguish between the needs to establish NEF values or EPNL values to a given confidence level, since the degree of variability and time required for measurement may be vastly different. For example, an air base may have a wide variation in the number of operations and in the choice of flight paths used on a day-to-day basis. Therefore, it may take a considerable period of time, perhaps several weeks, to establish a field NEF value to a given degree of confidence, since one can accumulate only one NEF value per 24 hours of measurement. However, one might well be able to determine noise levels for a given aircraft operation to a given confidence level in one or two days, if a large number of the desired operations occurs each day.

Variability in day-to-day NEF values will be directly related to variations in volume of operations and changes in use of flight paths, and may be heavily influenced by weather conditions which result in frequent changes in runway usage. Recent field measurements indicate that at relatively "close in" measurement positions at airports where there are few reversals of runway usage, NEF values will show moderate variability (standard deviations of the order of one to three dB). Measurements at airports where there are frequent reversals of runway usage can show much larger standard deviations on the order of three to five dB or more. In the later case, Figure B-1 shows that for a standard deviation of 5 dB, one would need approximately 20 days of measurements to establish the average NEF value within a 90% confidence interval of ± 2 dB.

Additional engineering guidelines for field noise measurements to confirm noise contours are given in Appendix D of Air Force Report AMRL TR-73-106 (listed in the Bibliography).

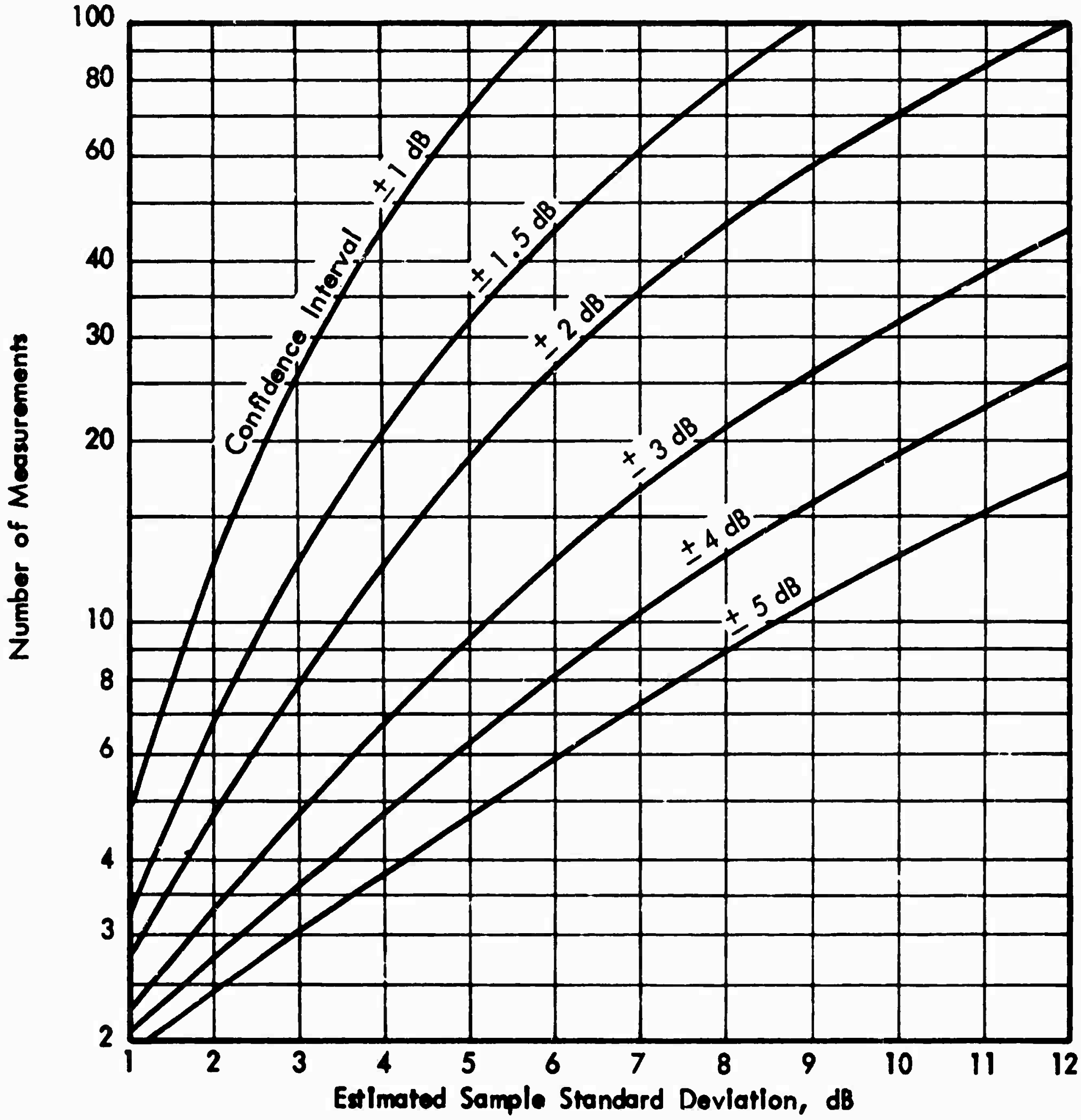


FIGURE B-1. NUMBER OF MEASUREMENTS NEEDED TO ASSURE A 90 PER CENT CONFIDENCE INTERVAL

*U.S.Government Printing Office: 1974 — 657-017/351